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Removal of Heavy Metals and Suspended Solids from Battery Wastewaters: Application of Hydroperm Cross-Flow Microfiltration

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Reading, PA

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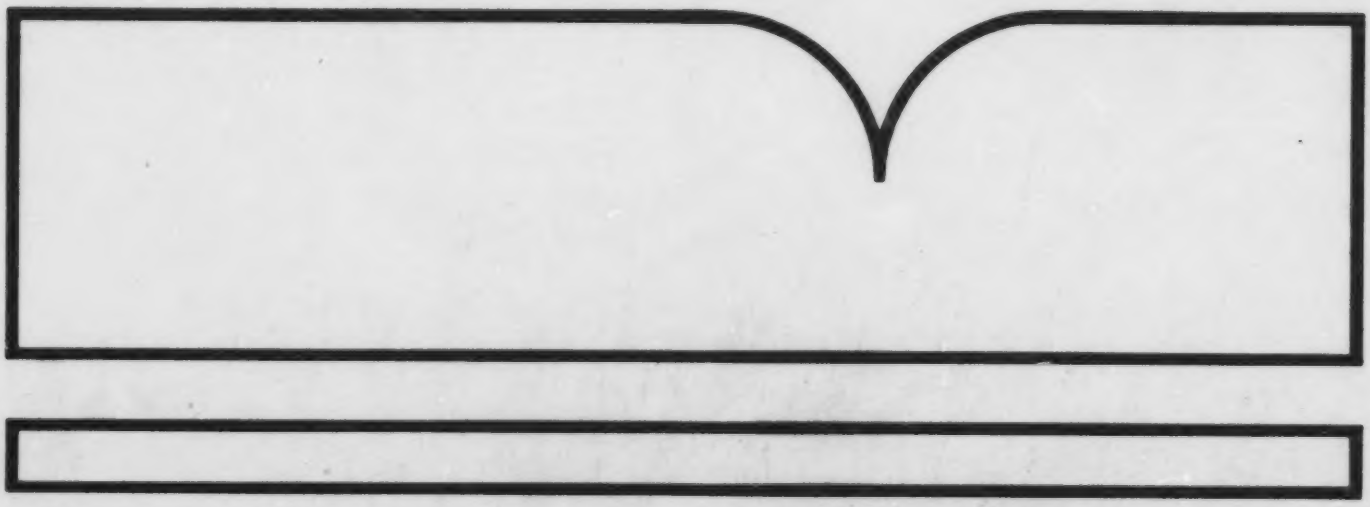

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REMOVAL OF HEAVY METALS AND SUSPENDED SOLIDS FROM BATTERY WASTEWATERS: APPLICATION OF HYDROPERM™ CROSS-FLOW MICROFILTRATION

by

Norman I. Shapira
Han-Lieh Liu
HYDRONAUTICS, Incorporated
Laurel, Maryland 20810
and
John Baranski
David Kurzweg
General Battery Corporation
Reading, Pennsylvania 19603

Grant No. S-805748-01

Project Officer

Charles Darvin
Nonferrous Metals and Minerals Branch
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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16. ABSTRACT

This project was undertaken to evaluate the capability of cross-flow microfiltration to remove suspended toxic metal and metal hydroxides from battery manufacturing wastewaters. The demonstration was conducted at the General Battery Corporation plant at Hamburg, Pennsylvania. A full scale system capable of processing 150,000 liters per day (40,000 gal/day) was constructed and installed at the General Battery facility.

The following conclusions were determined from the demonstration at General Battery: (1) Cross-flow filtration will effectively remove suspended solids and suspended metal hydroxides including arsenic hydroxide and antimony hydroxide from battery manufacturing wastewaters, (2) reasonable flux rates can be achieved with the use of the microfiltration membrane filters, (3) sludges of up to 35 percent solids can be easily generated significantly reducing the sludge generation rate. Suspended solid in feed ranging as high as 180,000 ppm were typically reduced to less than 5 ppm in the permeate. Lead was reduced from several hundred ppm in the feed to less than .10 ppm in the permeate. The Ph of the wastewater was maintained between 8 and 9.

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FOREWORD

When energy and material resources are extracted, processed, converted and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

A laboratory and full-scale demonstration field test program was conducted to demonstrate the feasibility and applicability of cross-flow microfiltration for the removal of suspended solids and toxic heavy metals from lead-acid battery production wastewaters. The results of that program are presented in this report. The results are being used within the Agency's Office of Research and Development as part of a larger effort to develop technically viable and cost effective control technologies for the nations industries. Industry can also use the results in dealing with their environmental problems. The Nonferrous Metals and Minerals Branch of the Energy Pollution Control Division should be contacted for any additional information concerning this program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati, Ohio

ABSTRACT

Laboratory and full-scale field tests have been conducted to demonstrate the applicability of the HYDROPERM™ cross-flow microfiltration system for the virtually complete removal of suspended solids, and for the removal of (suspended) toxic heavy metals from lead-acid battery production wastewaters.

The results of the program show that the system achieves virtually complete removal of suspended solids (the filtrate water has a suspended solids concentration of <5 ppm) regardless of the feed concentration. Lead is typically reduced to <0.1 ppm.

The waste is a mixture of sulfuric acid (~20%) from occational dumping of open-tank formation of the anode and cathode battery plates, rinse water from the plate washing facilities, and various floor drains from throughout the plant. The combined total of daily waste production is ~75,500 liters per day (20,000 Liquid gal/day).

The waste acid and rinse water mixture is neutralized with high calcium lime to convert the soluble metals to suspended metal hydroxide form. The microfiltration system is a treatment process which employs a physical principle of treatment for SS removal after chemical precipitation. The principal element of the system is a thermoplastic tubular filter (6 mm ID) constructed with a controlled porosity in the micron-size range. Relatively low feed pressures (1.05 kg/cm^2, ~15 psi) are employed, which are of significant interest in energy conservation.

The first phase of the study was to determine the proper porosity, construction material and diameter of the tubes by a series of tests which approximated the in-plant conditions as closely as possible. In addition, studies were conducted to optimize operating conditions (pressure and velocity).

The second phase of the study involved the installation and demonstration of a full-scale system. The area available for the equipment was very limited; however, due to the compactness of the system, the use of Hydroperm was much easier than installing conventional settling or clarification equipment.

During the full-scale field demonstration, samples were taken frequently and analyzed for pH, heavy metals, and solids. Suspended solids in the feed, ranging from tens of thousands of ppm to as high as 180,000 ppm, were typically reduced to <5 ppm in the permeate. Lead was generally reduced from several hundred ppm in the feed to ~0.02 to 0.10 ppm in the permeate, well below the effluent standards set forth by the state of Pennsylvania for discharge to natural waters (i.e., ≤0.14 ppm monthly average). Comparable reductions of other toxic heavy metals were achieved.

Fluxes in the range of 16,000-24,000 lmd* (400-600 gfd) were readily achieved. Permeate was produced at a rate of 11,000 to 17,000 liters/hour (3000 to 4500 gal/hour) by each of the two units. A sludge was produced with 20-35% suspended solids by weight.

Both from a flux and a filtrate quality standpoint, the test and demonstration programs indicate that the Hydroperm system is effective for treating battery manufacturing wastewaters for discharge. Reuse of the permeate is recommended for study.

It is anticipated that the microfiltration technology will have application in the removal of heavy metals from such industries as battery manufacture, metal finishing, metal refining, and other industries producing similar toxic wastes.

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* lmd = liters/square meter-day
gfd = gallons/square feet-day

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SECTION 1

INTRODUCTION

PURPOSE

This report presents the results of a research, development and demonstration program for the application of a HYDROPERM™ microfiltration system for the treatment of lead-acid battery manufacture wastewater effluents at the General Battery Corporation plant at Hamburg, Pennsylvania.

Hydroperm is a new method of suspended solids removal utilizing cross-flow microfiltration with thick-walled, porous plastic tubes. These tubes, whose wall thickness, inside diameter, porosity, and pore-size distribution can all be closely controlled, can be selected for a particular wastewater so as to obtain optimum performance. The filtration characteristics of the tubes combine both the "in-depth" filtration aspects of multimedia filters and the "surface" filtration aspects of membrane filters. For example, while the removal of micron- and submicron-size particles is often difficult or impossible with conventional gravity settling or through-flow filters, the cross-flow microfiltration tubes are capable of virtually complete removal of such particles.

In the treatment of both domestic and industrial wastewaters, the removal of suspended solids is a required operation which arises under a variety of circumstances. For example, this unit operation is often essential as a pretreatment step prior to undertaking further advanced treatment. Fine-solids removal is also often necessary as a "polishing" step after chemical or biological treatment processes. There are several existing physical treatment processes available for this purpose, such as gravity clarification, multimedia filtration, etc. However, most of these processes have inherent disadvantages in dealing with fine and difficult-to-settle solids. In addition, neither of these processes produces a highly dewatered sludge.

CROSS-FLOW FILTRATION

For removal of suspended solids, two types of filtration processes have been widely used: (1) the through-flow (e.g., multimedia) filter; and (2) cross-flow[1,2] filtration (e.g., ultrafiltration and reverse osmosis). Although they can remove

some of the suspended solids, conventional through-flow filters have the disadvantage of requiring frequent backwashing, since the filtered particles continuously accumulate on, or actually enter, the filtration barrier. Through-flow filtration is, by its very nature, a batch process, with the flux declining relatively rapidly when the driving pressure differential across the filtration barrier is held constant.

On the other hand, in cross-flow filtration, the direction of the feed flow is parallel to the filter surface, so that accumulation of the filtered solids on the filter medium can be minimized by the shearing action of the flow. Thus, cross-flow filtration affords the possibility of a quasi-steady state operation with a nearly-constant flux when driving pressure differential is held constant.

MICROFILTRATION

It is relevant to point out that cross-flow microfiltration, which is intended primarily for the removal of suspended solids, is significantly different from membrane ultrafiltration (UF) or hyperfiltration (RO) which remove substances on the molecular level in addition to suspended solids. In UF, higher filtration pressures, 3.5-10.5 Kg/cm^2, (50-150 psi) are used, with even higher pressures (from 42-82 Kg/cm^2, 600-1200 psi) for RO, compared with only 1.05 Kg/cm^2 (15 psi) for microfiltration. Furthermore, UF and RO employ relatively thin membranes, compared with the in-depth, relatively thick-walled (~1 mm) Hydroperm microfilters. As a result, power requirements as well as both capital and operating costs are higher for membrane systems than for cross-flow microfiltration.

R,D & D PROGRAM

This report describes the results of a two-phase program to demonstrate the applicability of the Hydroperm microfiltration system for the removal of toxic heavy metals from lead-acid battery manufacturing wastewaters after the metals have been chemically precipitated. This program was conducted under the sponsorship of the United States Environmental Protection Agency's Industrial Environmental Research Laboratory in Cincinnati, Ohio, under a cooperative agreement to General Battery Corporation, Reading, Pennsylvania. The Hydroperm research, development and demonstration program was conducted by HYDRONAUTICS, Incorporated, under a contract with General Battery Corporation. The program was initiated in August 1978 and terminated in June 1980. The results reported herein include both the Phase I laboratory test program and the Phase II on-site demonstration of a full-scale microfiltration system at the General Battery Corporation plant at Hamburg, Pennsylvania.

The two-phase program is outlined below:

The objective of the Phase I laboratory program was to test, evaluate and optimize Hydroperm tubes for the effective treatment of battery manufacture wastewaters. Since a unique feature of the tubes is that they can be selected for optimum performance with specific wastewaters by varying the tube material and pore structure as well as the system operating conditions, a principal objective of the proposed program was to conduct such optimization studies.

The objectives of the Phase II program were to design, construct, install and demonstrate a full-scale Hydroperm system at the General Battery Corporation plant in Hamburg, Pennsylvania.

BATTERY WASTEWATERS

The wastewaters from lead-acid battery manufacturing are highly acidic (pH ~1), and contain a number of toxic heavy metals, primarily lead, in concentrations varying from 20 to 500 ppm. Other metals in the waste include Cu, Ni, Zn, As and Sb.

Prior to installation of the Hydroperm wastewater treatment system at the General Battery Corporation plant in Hamburg, Pennsylvania, acid wastewaters from that plant were treated with lime, and then transported ~20 miles by tank truck 2-3 times/day to the wastewater treatment facility at the General Battery Corporation Reading plant, where a conventional three-step process is employed in a 24 hr/day operation, including: lime treatment, crystalization and flocculation; and primary and secondary settling with clarifiers and lagoons.

WATER QUALITY REGULATIONS

For discharge to the environment, the State of Pennsylvania water quality regulations require that:

- Lead be reduced to a monthly average of 0.14 ppm. with a daily maximum of 0.5 ppm.
- SS be reduced to a monthly average of 20 ppm, with a daily maximum of 40 ppm.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Cross-flow microfiltration is an effective technology for the treatment of suspended solids in wastewaters from the production of lead-acid batteries.

PERMEATE QUALITY

Suspended solids in the feed ranging to well over 150,000 ppm are typically reduced to <3 ppm in the permeate. Lead in the feed in the range of several hundred ppm is typically reduced to ~0.02-0.1 ppm in the permeate. Other toxic heavy metals, such as Cu, Ni, Zn, As and Sb are removed with comparable effectiveness. Although, at the moment, the filtrate is discharged directly to a local stream, the quality of the filtrate in terms of suspended solids and toxic heavy metals is such that reuse is also a possible option but requires further study.

FLUX

One Hydroperm unit with 16.7 m^2 (180 ft^2) of filter surface area achieves a plateau flux value of 16000 lmd (400 gfd), equivalent to 180 lpm (50 gpm) of permeate production with lime-treated lead-acid battery wastewater.

SLUDGE

Sludges in the range of 20-35 percent suspended solids by weight are regularly produced by the Hydroperm system.

ECONOMICS

The capital cost of the Hydroperm unit alone is projected to be in the range of $0.13/liter-day ($0.50/gal-day). Including costs of transportation, installation, recirculation tank, permeate tank, etc., capital costs would still be $0.26/liter-day ($1.00/gal-day). Operating costs are projected to be $0.13/1000 liter ($0.50/1000 gal).

RECOMMENDATIONS

Cross-flow microfiltration should have broad application for removal of suspended solids and (suspended) toxic

heavy metals in a wide range of industries, including battery manufacture, metal finishing, smelting and refining, and other industries with similar wastewaters.

SECTION 3

CHARACTERISTIC FEATURES OF CROSS-FLOW MICROFILTRATION

TUBE CHARACTERISTICS

The method of advanced treatment of lead-acid battery manufacture wastewaters described in this report is based on cross-flow microfiltration. The principle element of the system is a thick-walled hollow tubular filter (~6-9 mm ID) made of thermoplastic material and containing micron-size pores. Even at relatively low filtration pressures, 1.05 Kg/cm^2 (15 psi), the Hydroperm tubes are capable of significant removal of suspended solids, while maintaining reasonably high permeation rates.

These tubes can be made from a variety of extrudable thermoplastics, such as nylon, polyethylene, and polypropylene by a proprietary manufacturing process. A brief summary will be given here in order to help set in proper perspective, the test results described later in this report.

The filtration characteristics of Hydroperm tubes combine both the "in-depth" filtration aspects of multimedia filters and the "surface" filtration aspects of membrane ultrafilters. For example, in a manner similar to multimedia filters, the tubes may allow some of the smaller particles in the waste streams to actually penetrate into their wall matrix. However, it should be noted that the pore structure of the tubes differs from those of membrane ultrafilters in that the pore sizes of the former are of the order of several microns with the "length" of the pores being many times their diameters. It is relevant to emphasize at the outset that because of this unique combination of "in-depth" and "surface" filtration aspects, these tubes display performance characteristics of removal of both suspended and dissolved solids. Thus, while the tubes are primarily designed for the separation of suspended solids from the feed, they frequently achieve substantial levels of dissolved solids separation, because of the formation of a dynamic membrane on the inside walls of the tubes. The characteristics of this membrane vary with the characteristics of the solids-content of the feed. The thickness of the membrane is controlled by the shear exerted by the circulation flow. The concentrated solids are not deposited inside the tubes, but settle

out in a settling cone (see Figure 1) as permeate is removed from the feed.

PORE-SIZE

A schematic view of cross-flow filtration through the tubes is shown in Figure 2. The feed flow is through the inside of the tubes at relatively low pressure, 1.05 Kg/cm^2 (15 psi) and the filtrate permeation occurs through the relatively thick (~1 mm) tube walls. Pore-size distributions of two typical Hydroperm tubes are shown in Figure 3. Tube I has a rather "flat" distribution with the pores ranging in size from 2 microns to 10 microns. On the other hand, Tube II has a "peaked" distribution, with most of the pores being in the 2-micron range. It should be noted that the pore-size distributions shown in Figure 3 are initial values, since the pore-size distribution of the tubes undergoes a change during the filtration process because of the penetration of small particles into the tube wall.

PORE STRUCTURE

Two views of the pore structure of a typical Hydroperm tube are shown in Figure 4. These photographs were taken with the aid of a Scanning Electron Microscope and are of a transverse section of the tubes. The view in 4a has a magnification factor of two hundred, while that in 4b has a magnification factor of one thousand. The open-cell, reticulated nature of the pore structure can be appreciated from these photographs.

FILTRATION PROCESS

The features described above (together with operating conditions) are of importance in determining the performance of a given tube when it is used with a specific wastewater, as can be seen by considering a relatively simple model for the filtration process described below.

In general, any effluent from which suspended solids removal is desired will contain a range of particulates, varying in diameter from colloidal dimensions to many microns. When such effluents are circulated through the inside of a porous tubular filter such as Hydroperm, the solids particles will be driven, with the permeating flow, toward the wall. Thus, the concentration of the particles in regions close to the wall will tend to steadily increase, this tendency being delimited by the turbulent diffusion of the particles from regions of high concentration to those of lower concentration (that is, away from the walls and toward the center of the tube).

This turbulent diffusion (which tends to decrease the

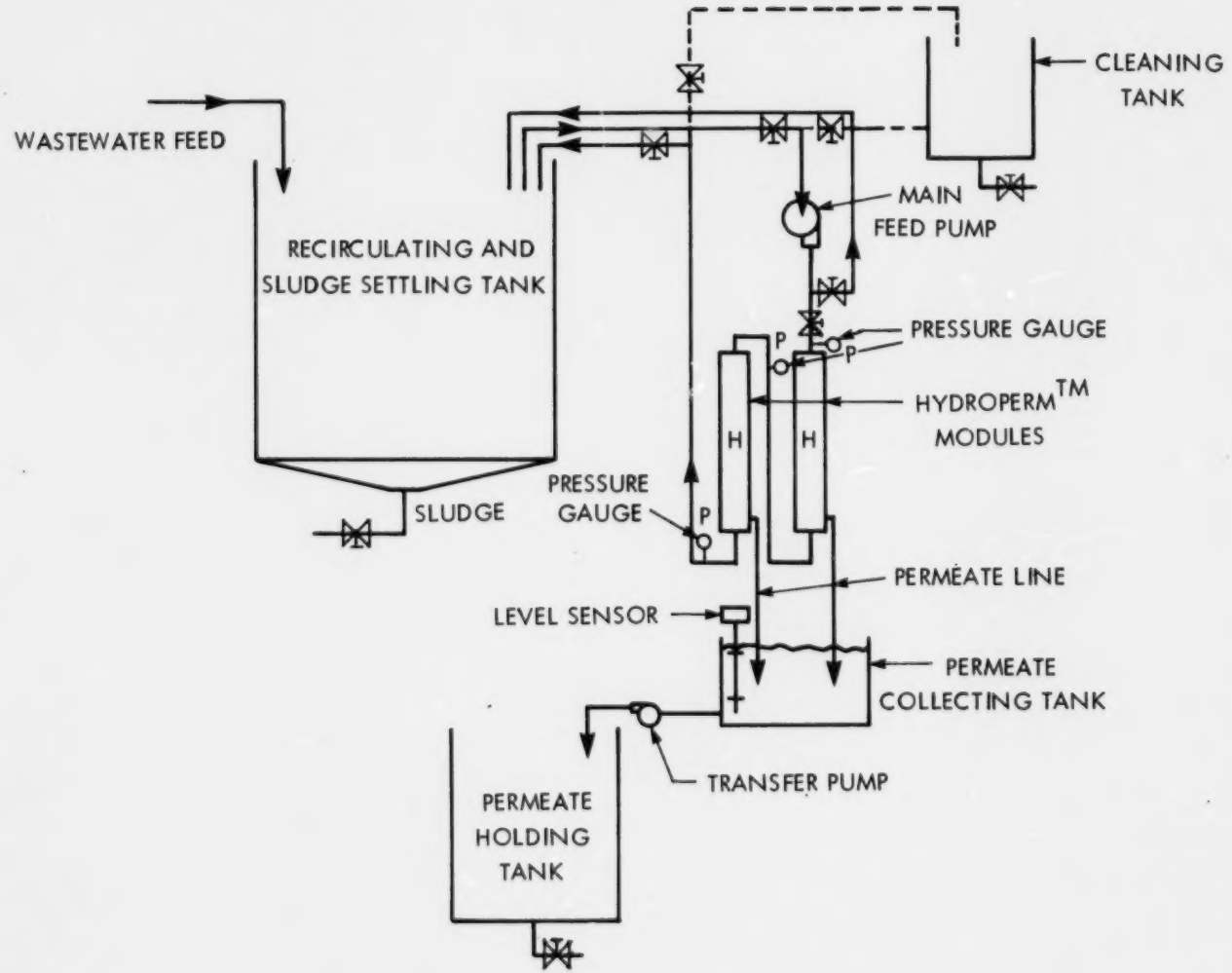


Figure 1. Microfiltration system schematic diagram.

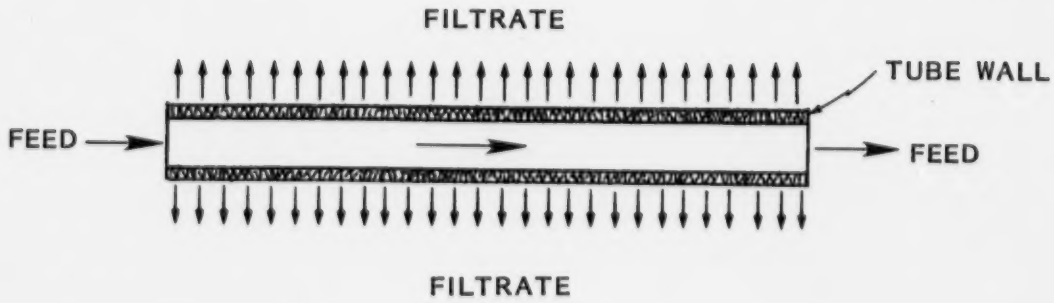


FIGURE 2 - CROSS-FLOW FILTRATION SCHEMATIC

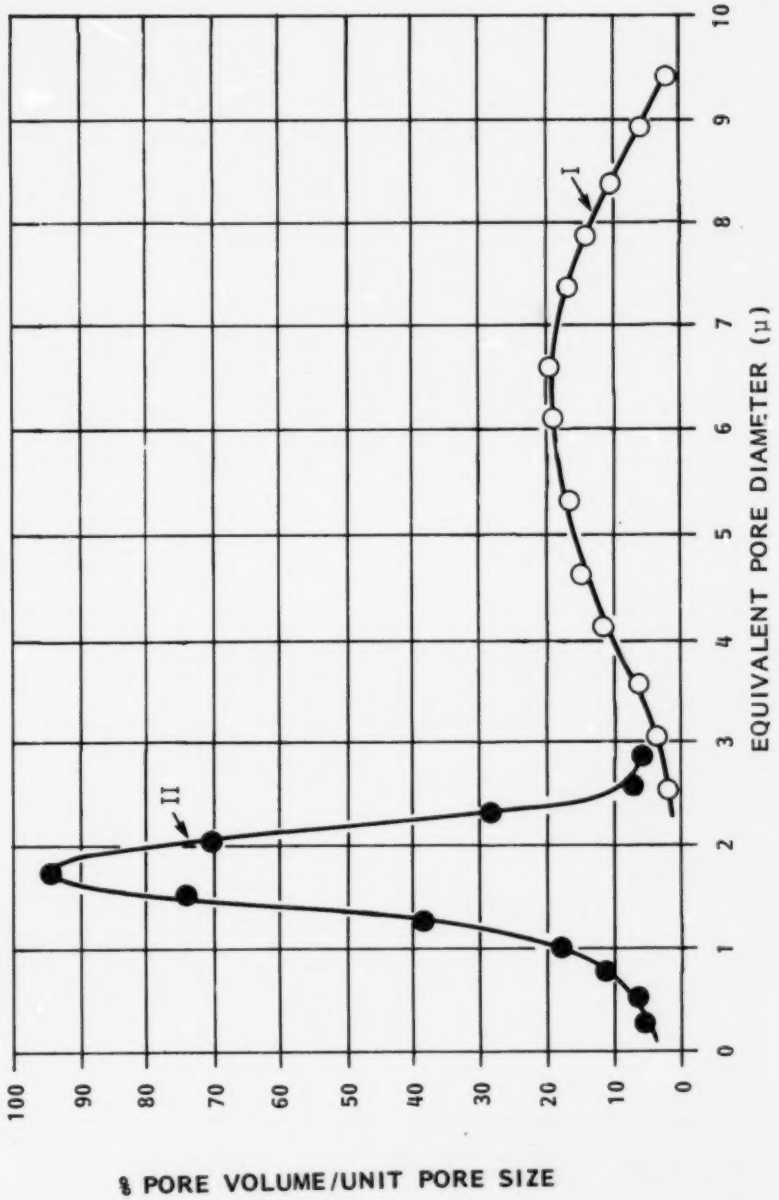
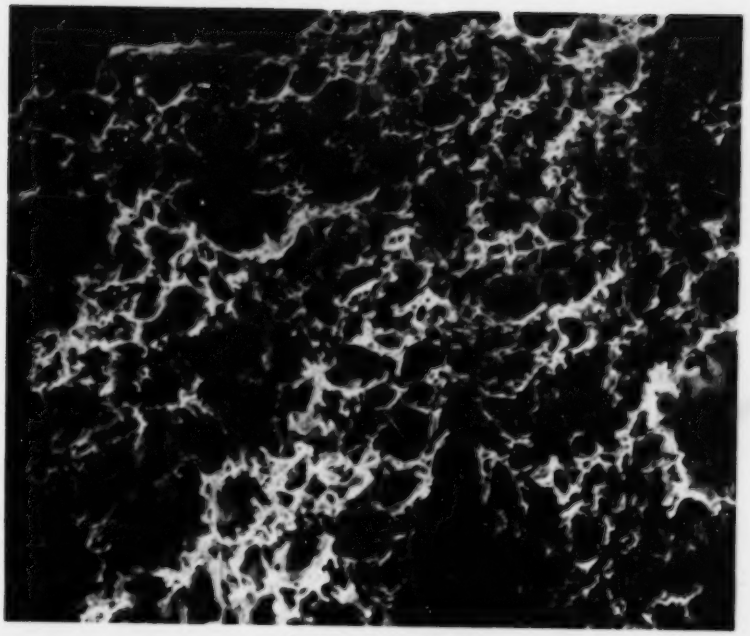
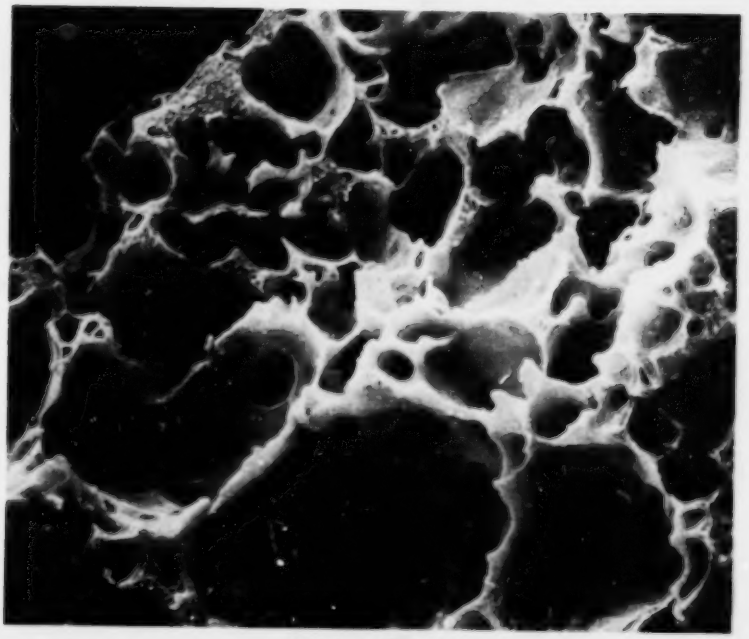


Figure 3. Typical pore-size distribution.



a) S.E.M. 200X



b) S.E.M. 1000X

Figure 4. Electron microphotographs of pore structure - transverse section.

particle concentration near the wall) is dependent on the shear stress that is exerted on the walls by the feed circulation, and hence its velocity. On the other hand, the permeation rate (which tends to increase the particle concentration near the wall) depends on the pressure differential across the filter surface (Poiseuille's law) as well as the effective pore structure of the tubes (Darcy's law). A quasi-steady-state profile of the concentration of the particles will be established near the wall, when the opposing tendencies mentioned above exactly balance each other. The resulting "particle polarization" in this case is analogous to the "concentration polarization" of solutes which occurs close to the walls of ultrafiltration and reverse-osmosis membranes.

Because of the in-depth filtration characteristics of the tubes, other factors also come into play. Feed particles which are smaller than the largest pore size of the tubes may actually enter the wall matrix, while particles which are larger than any of the pores in the tubes will be retained at the walls. Some small particles which enter the tube matrix will ultimately become entrapped within the wall of the tube because of the irregular and tortuous nature of the pores, but will not pass through. Thus, as filtration proceeds, the pore structure of the tube as well as its permeability will undergo a gradual change due to the penetration of some of the pores by the intruder particles. However, the tendency of new particles to enter the tube matrix will decrease rapidly as the dynamic membrane forms on the walls due to the particle polarization described earlier.

Even from the relatively simple, qualitative discussion given above, it is clear that the filtration performance is influenced not only by such factors as the filtration pressure, circulating flow velocity, temperature (which changes the fluid viscosity and, hence, by Darcy's law, the permeation rate), but also by the pore-size distribution and pore structure of the tubes, as well as the particle-size distribution in the wastes.

SECTION 4-A

WASTEWATER CHARACTERISTICS OF LEAD-ACID BATTERY PRODUCTION

INTRODUCTION

This discussion deals only with the production of the lead-acid type of secondary batteries, and is based on information contained in the Environmental Protection Agency Report Number EPA/530/SW-102C, dated January 1975, entitled "Assessment of Industrial Hazardous Waste Practices, Storage and Primary Battery Industries," and in the Battery Council International 1976-1977 Yearbook.

INDUSTRY PROFILE

General

The secondary battery industry consists of 132 companies with 219 plants. Lead-acid storage batteries are produced in 202 of these plants. A "typical" lead-acid plant employs 100 to 250 people, is 20 years old and produces 8,233,300 kg of batteries annually. The "typical" plant is usually located within a large population center (usually a metropolitan area) with access to a municipal water and sewage system. In 1975, the secondary battery industry in the United States produced 49,656,361 starting, lighting and ignition (SLI) batteries.

Raw Materials, Water Usage and Disposition

In 1975, the battery industry used approximately 584 thousand tons of lead. This lead consumption represents approximately 47.5 percent of the 1975 lead consumption in the United States.

The industry employs two methods of manufacturing lead-acid batteries, referred to as the dry charge manufacturing process or wet charge manufacturing process. The dry charge manufacturing process prepares electrode elements in an electrically charged acid bath. After the element is formed it is drained, rinsed with fresh water and dried. The dried elements are assembled in a battery case, with battery posts welded into place and a cover placed on the case to seal the battery.

The wet charge battery is manufactured by placing the elements in the battery case, then welding the elements together

with the posts connected to them. The battery is then filled with acid and undergoes the same forming process as the dry batteries. After forming, the acid is dumped (and generally recovered), fresh acid is added, and the battery is boost-charged. The battery is then washed, painted, and shipped.

The type of wastewater produced by lead-acid battery manufacturing is given in Table 1. The present effluent standards applied in Pennsylvania are shown in Table 2.

TABLE 1. WASTEWATER FROM A "TYPICAL" LEAD-ACID BATTERY MANUFACTURING PLANT

Parameter	"Typical" Plant
pH	~1.0
Lead Content (ppm)	20-500
Acid Concentration %	4
Suspended Solids (ppm)	<3,000
Dissolved Solids (ppm)	<2,000

TABLE 2. PENNSYLVANIA NPDES PERMIT

	Monthly Average (ppm)	Daily Maximum (ppm)
Suspended Solids	20	40
Lead	0.14	0.50
pH	6-9	6-9

BATTERY WASTEWATERS

The wastewaters from lead-acid battery manufacturing are highly acidic (pH ~1), and contain a number of toxic heavy metals, primarily lead, in concentrations varying from 20 to 500 ppm. Other metals in the waste include Cu, Ni, Zn, As and Sb.

In the manufacture of industrial and automobile batteries, wastewater is generated from the washdown of sulfuric acid spills which occur during battery filling and the washdown of the stations where lead oxide pasting and forming are done. Contact cooling wastewater from the manufacture of lead oxide also contains oil and grease. In addition, used batteries containing spent electrolyte (sulfuric acid) may also be processed on site. The tops of batteries are sheared off and the contents dumped. The lead and lead compounds are separated from the electrolyte which is mixed with wash water. This wastewater is a major effluent. In addition, wastewaters can also result from: secondary smelter operations; as leachate from sludge and slag landfill sites; and as washdown and scrubber water from air pollution control equipment.

SLUDGE

The character of the sludge from wastewater treatment is largely determined by the type of treatment process. Current lead-acid battery treatment practices include neutralization, precipitation, sedimentation, and filtration. As of 1975, three-fourths of the lead-acid manufacturing plants (150 plants) within the United States neutralized their wastewater and discharged directly to waterways or municipal treatment plants. Fourteen plants used lime treatment to produce a calcium-sulfate-lead sludge, while the remaining plants use caustic to produce a lead hydroxide-sulfate sludge. The sludge from all the treatment processes must be disposed of in relatively secure landfill sites to reduce the potential for toxic contamination by migrating lead, and positive safeguards must be considered when disposing of lead sludge due to its high lead concentration. Therefore, reduction of sludge to minimum volumes is an important economic consideration.

SECTION 4-B

CONVENTIONAL TOXIC HEAVY METALS TREATMENT

BACKGROUND

As mentioned earlier, the principal pollutants in battery manufacturing wastewaters are toxic heavy metals. When these wastewaters are discharged either into the publicly-owned treatment works or natural streams, they have to meet either the pretreatment standards of the POTW or the water quality standards of the receiving water body. In either case, the intention is to reduce the health and environmental risk of pollution caused by discharging hazardous wastewaters. As a general practice, manufacturing wastewaters must be treated before being discharged. Neutralization and precipitation of heavy metals in wastewaters has been widely used, after which a number of processes can be employed for removal of the suspended solids.

In an evaluation of treatment technology for water reuse and recycling, sponsored by OWRT[3], it was suggested that "lime precipitation tends to be more effective than the addition of alum or ferric chloride." Both precipitants, such as lime, and coagulants, such as alum have frequently been used in metals wastewater treatment processes. A brief discussion of the precipitation process follows.

PRECIPITATION OF HEAVY METALS

Heavy metals are usually allowed to precipitate as their hydroxides. Since these precipitates are not usually stoichiometric hydroxides, but oxides of rather indefinite composition with various amounts of more-or-less loosely bound water, the term "hydrous oxides" is more precise. Most hydrous oxides have low solubility, therefore they can be precipitated by adjusting the pH to an appropriate value, which differs according to the particular metal and is most critical for amphoteric metals such as lead, which dissolve at both low and high pH. Alkali for precipitating metal hydroxides may be soda ash (Na_2CO_3), lime ($Ca(OH)_2$) or caustic soda (NaOH). The hydrous oxides (metal hydroxides) are in general, gelatinous, slow to settle, and difficult to filter with conventional filtration. The sludges formed are very watery, often containing <5% solids, and their disposal presents problems. Recently, sulfide precipitation has also been investigated. After these metal hydrous oxides have been precipitated, these solids can be removed from the wastewater with varying effectiveness through

one of several liquid/solids separation techniques, i.e., gravity separation, centrifugation, filtration, etc.

CONVENTIONAL TREATMENT

To enhance the settling characteristics of the suspended solids, flocculating agents are occasionally employed. In the flocculator, the wastewater is agitated gently to allow the precipitated solids to coagulate with the flocculant, such as polymers, alum or ferric sulfate. In conventional treatment, the wastewater then enters the clarifier where most of the solids settle out. The solids in the underflow can be discharged to a holding tank for thickening and disposal.

The difficulties in this conventional treatment process lie in the relatively inefficient nature of the gravity separation process. The solids removal efficiency depends on the settling rate of the suspended solids in the wastewater. Some of these solids settle very slowly because of their small size and their slight density difference compared with the water. Large land areas are required for lagoon clarification. Furthermore, economical design of the clarifier limits the retention time in the settling ponds, and some level of suspended solids will usually appear in the overflow.

The gravity settling technique can only separate suspended solids, and not the dissolved solids. Since every metal has its own solubility dependency on pH, control of pH at one value in the treatment process may not be enough to precipitate all of the dissolved metals, and the effluent in the treated wastewater will usually still show some trace of dissolved heavy metal contamination.

The sludge from conventional clarifiers typically contains very low solids concentrations of ~0.5 to 5 percent; overflow from the sludge tank is recycled to the clarifier. Usually metal hydroxide solids will concentrate only to approximately 3- to 5-percent solids in these tanks if given adequate retention time. The tanks also provide storage time and volume for the sludge before shipment to the disposal site, but require large spaces.

Further concentration of the sludge by conventional methods requires the use of mechanical dewatering equipment. Centrifuges, rotary vacuum filters, belt filters, and filter presses have been used to dewater metal hydroxide sludges.

CROSS-FLOW MICROFILTRATION

As shown later in this report, the cross-flow microfiltra-

tion process achieves virtually complete removal of suspended solids, and is more effective than conventional physical treatment of the wastewater by clarification. In addition, sludge concentrations of 20-35% by weight are produced.

SECTION 5

EXPERIMENTAL APPARATUS AND LABORATORY TEST PROCEDURES

TYPES OF LABORATORY TESTS

The laboratory tests described in this report consisted both of tests with single tubes and with modules containing a "bundle" of several tubes. A schematic view of a typical single-tube test loop is shown in Figure 5. As indicated in the figure, the loops normally include a small feed reservoir of 18.9-liter (5-gallon)* capacity, a circulating pump, a flow meter, pressure gauges to measure pressure drops over the length of the tubing being tested and appropriate valving.

Basically, three different modes of operation are used when carrying out the laboratory tests. The first involves "constant concentration" operation, with the permeate remixed into the feed reservoir, so that (except for evaporation losses) the volume of the recirculating feed, as well as its suspended-solids concentration, remain constant. The feed in the reservoir is replaced at appropriate intervals to eliminate changes in characteristics due to biological activity and/or constant recirculation.

In the second "concentration" mode of operation, a batch-wise process of a field system is simulated. Here the permeate is removed and collected in a separate reservoir, so that the volume of the circulating feed continuously decreases while its suspended-solids concentration continuously increases. The tests are continued until a specified feed concentration is reached or until the volume of the feed becomes so low that adequate pump suction from the reservoir can no longer be maintained.

In the third mode of operation, a "continuous" field process is simulated. As permeate is withdrawn by the filtration process, comparable amounts of new feed are added. Periodically, sludge is removed.

TEST PROCEDURES

Essentially, the tube selection test procedure consists of

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* A 208-liter (55-gal) drum reservoir was actually used in this test program.

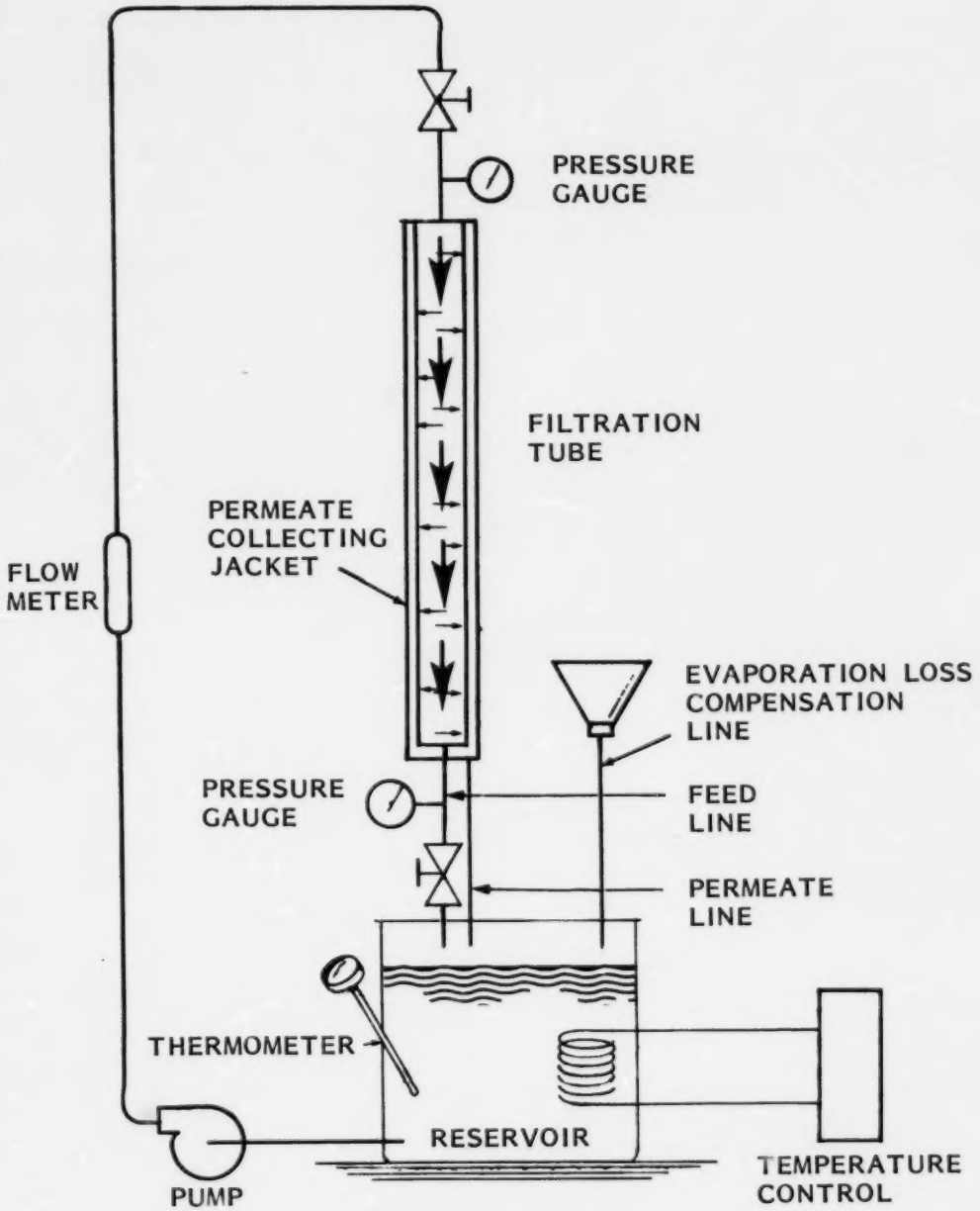

Figure 5. Schematic of a single-tube test loop.

performing several relatively short duration tests (about 50-100 hours of constant concentration filtration operation) with a number of short lengths (about 45 cm long) of Hydroperm tubes of differing materials and pore structures. It has been found that, through such a systematic series of tests, it is usually possible to select optimum tubes and operating conditions for the given waste feed under consideration. Optimization is measured in terms of permeate quality and flux, liters per square meter of filter-surface-area per day, lmd (or gallons per square foot per day, gfd).

Two types of laboratory tests are usually conducted. The first is a preliminary determination of effective operating conditions and cleaning procedures. This type of test has the objectives of: investigating various operating velocities to achieve a high filtrate flux and slow initial flux decline; selecting the best tube type; and determining the most promising cleaning method for maintaining and flux at a high value for long periods of time. During these tests, both the filtrate and the concentrate are usually remixed in the feed reservoir in order to keep the feed conditions the same throughout the duration of the test.

The second type of test is the long-term module and concentration test. In these tests, an optimum type tube is selected for use in a multi-tube module in both long-term and concentration tests designed to simulate field operation; that is, during the latter stage of this test the filtrate is removed from the feed reservoir. From this test, information is obtained on long-term filtrate flux and permeate quality, the degree of concentration of the feed that can be obtained, and the ability to operate without clogging.

LABORATORY SETUP

The original test setup (Figure 6) at the HYDRONAUTICS laboratory included single-tube test loops equipped with 7.6-liter (2-gallon) reservoirs. It was decided to modify this test setup by incorporating a 208-liter (55-gallon) reservoir, based upon the following reasoning.

In the field unit at Hamburg, 90,800-liters (24,000-gallons) of waste were planned to be processed per day by pumping at the rate of 946 lpm (250 gpm) through each of two parallel units of two Hydroperm modules each. The waste acid is collected and neutralized in a reaction tank of about a 60,600-liter (16,000-gallon) capacity. From there it is transferred to a 37,800-liter (10,000-gallon) cone, from which the feed is recirculated through the system. Thus the average flushing time of the wastes through each unit is 40 minutes (10,000 gallons/250 gpm). It was considered important that the characteristic circulating field flow time be duplicated in any small-scale

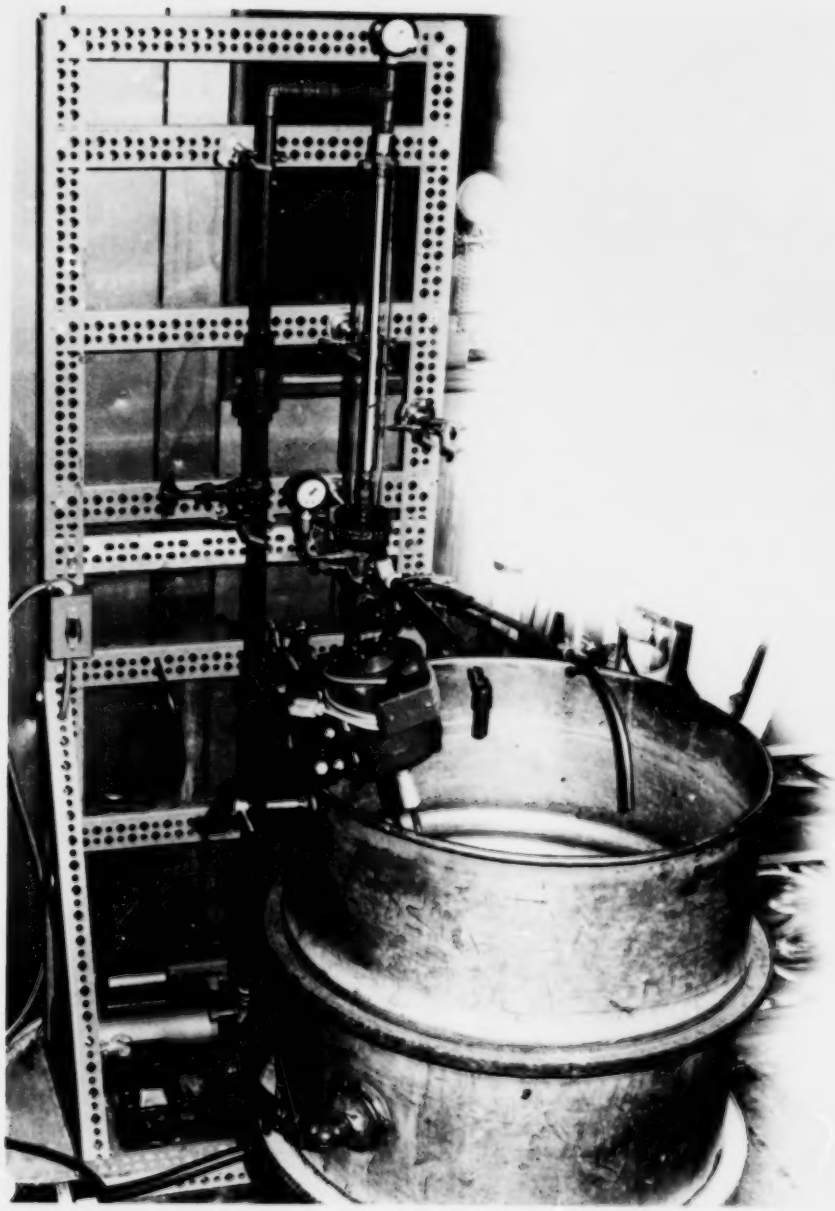

Figure 6. Laboratory test set-up.

laboratory test.

Since the circulating flow rate through a single 6-mm ID tube at 2.13 m/s (7 ft/sec) velocity is 3.8 lpm (1 gpm), the volume of the holding container required is about 150-liters (40-gallons). For a 9-mm ID tube with a circulating flow rate of 8.3 lpm (2.2 gpm), at 2.13 m/s (7 ft/sec) velocity, the holding container volume required is about 208-liters (55-gallons). Therefore it was clear that the standard 7.6-liter (2-gallon) tank in the test loop was inadequate, and it was modified by replacement with a 208-liter (55-gallon) holding tank. This test setup is shown in Figures 6 and 7.

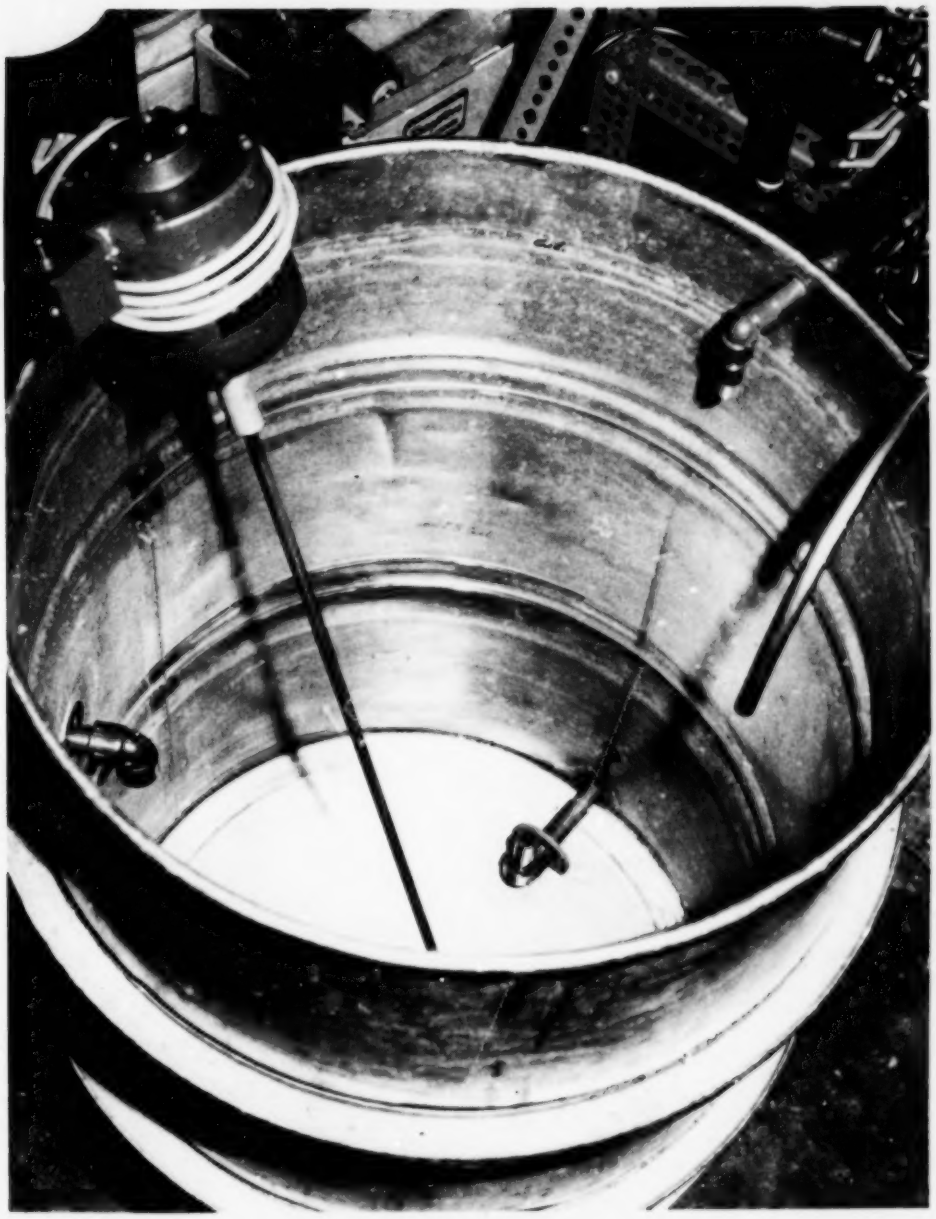

Figure 7. Laboratory test set-up.

SECTION 6

PHASE I LABORATORY TEST PROGRAM AND RESULTS

INTRODUCTION

Purpose

The purpose of this R,D and D program was to demonstrate the applicability of the cross-flow, microfiltration system for the removal of suspended solids, lead and other toxic heavy metals from lead-acid battery manufacturing wastewaters. The objective was to achieve a filtrate of adequate quality for discharge to the environment while maintaining economically reasonable flux levels. This section covers the work conducted under Phase I, Laboratory Investigations.

Tests

Eight single-tube tests were required to have been conducted for the purpose of selecting tube materials, pore structure, and operating parameters so as to optimize Hydroperm performance in terms of flux and permeate quality. As shown in Table 3, a total of thirteen single-tube tests were actually conducted.

SUMMARY OF RESULTS

The results of the test program, as described in more detail later in this report, were successful and, exceeded the original projections in terms of flux and permeate quality. Forty-hour plateau flux levels well in excess of 8000 lmd (200 gfd) were demonstrated in the Phase I laboratory program. These represent integrated 40-hour flux values probably in the range of over 12,000 lmd (300 gfd). Furthermore, with periodic cleaning of the tubes, fluxes in the range of 7700-9700 lmd (190-240 gfd) were obtained after a range of 114-164 hours of operation. In addition, when operating at optimum pH (~8.5-9.5) the quality of the permeate was excellent in terms of heavy metals removal, as shown later in this report (Tables 5, 6-A and 6-B). For example, Pb was typically reduced from >10 ppm in the feed to as low as <0.01 ppm in the permeate with median values in the range of 0.06~0.09 ppm. Similar results were achieved for other metals, with typical permeate values of: 0.05 for Cu; 0.05 for Ni; <0.1 for Zn; <0.002 for As; and ~0.3 for Sb. Suspended solids were typically reduced from >30,000 ppm in the feed (after lime treatment) to <10 in the permeate.

TABLE 3. SUMMARY - PHASE I TESTS AND FLUX RESULTS

Test No.	Tube						Feed Type	40-Hour Flux		Final Time		
	No.	Type	Material	I.D. (mm)	V					Flux		Time (hr)
					m/s	f/s		lmd	(gfd)	lmd	(gfd)	
G-1	6-26-78-II	2-9μ	NY	6	2.13	(7)	Limed Acid	23,600	(580)	20,000	(490)	90-hr
G-1A	3-22-77-II	1-3μ	NY	6	2.13	(7)	Limed Acid	Very low (est)		22,000	(55)	2-hr
G-7	6-26-78-II	2-9μ	NY	6	2.13	(7)	Supernatant alone	(N/A-1 hr test)		5,000	(124)	1-hr
G-8	6-26-78-II	2-9μ	NY	6	2.13	(7)	w/$CaSo_4$ Solids added Supernatant	5,500	(135)	9,400	(230)*	48-hr
G-2	6-26-78-II	2-9μ	NY	6	1.22	(4)	Limed Acid	2,000	(50)	9,800	(240)*	114-hr
G-3	6-26-78-II	2-9μ	NY	6	1.22	(4)	Limed Acid	9,800	(240)	6,100	(150)*	100-hr
G-4	6-26-78-II-u	1-12μ	NY	6	1.22	(4)	Limed Acid	2,800	(70)	8,100	(200)*	50-hr
G-10	6-26-78-II	2-9μ	NY	6	1.22	(4)	Limed Acid with Floc	14,600	(360)	12,000	(290)	70-hr
G-9	11-16-78-III	2-9μ	NY	4	2.13	(7)	Concentration Test Limed Acid	19,500	(480)	7,700	(190)	164-hr
G-9A	11-16-78-III	2-9μ	NY	4	2.13	(7)	Concentration Test Limed Acid	(Continuation of Test 9)		5,400	(133)	165-hr
G-6	6-26-78-III	2-9μ	NY	9	1.22	(4)	Limed Acid	7,100	(175)	2,600	(65)	92-hr
G-11	6-26-78-III	2-9μ	NY	9	1.22	(4)	Limed Acid	10,600	(260)	9,200	(225)*	160-hr
G-5	1-24-77-II	3-7μ	POLY	6	1.22	(4)	Limed Acid	600	(15)	400	(10)	45-hr

NOTE: All tests were conducted at 0.35 kg/cm² (5 psi)

* After cleaning

SINGLE-TUBE TEST PROGRAM

Test Parameters

In the test program, a systematic study was conducted, involving variation of a number of parameters including tube characteristics and operating conditions, as listed below:

(1) Tube material: nylon and polyethylene

(2) Tube diameter: 4-mm, 6-mm, and 9-mm ID

(3) Velocity: 1.22 m/s and 2.13 m/s (4 ft/sec and 7 ft/sec)

(4) pH: 7 - 10

(5) Three pore-size distributions

(6) Pressure was maintained at 0.35 kg/cm^2 (5 psi)

(7) Temperature was ambient, and all data in the figures are standardized at 35°C

The wastewater used for the tests described herein was obtained from the General Battery Corporation plant at Hamburg, Pennsylvania. The raw wastewaters typically contained ~1500-1900 mg/ℓ of total solids with 20-200 mg/ℓ of suspended solids and 10-20 mg/ℓ of lead. When received at the Hydroperm laboratory, the wastewater had a pH of ~1.0. Toxic heavy metals included Pb, Cu, Zn, Ni, Sb and As. The dissolved metals were precipitated at a range of pH's by adding hydrated lime. The best results in terms of lead precipitation were obtained at a pH of 8.5-9.5. After lime addition, TS values increased to ~45,000 mg/ℓ in the feed, most of which were in the form of SS (~40,000 mg/ℓ).

Thirteen single-tube tests of up to 160 hours in duration were performed with the lime-precipitated waste described above. In all but one of the tests the filtrate was remixed with the feed, which resulted in a "constant concentration" mode of operation. One test was performed with increasing suspended solids from the feed until an 85% reduction in the total volume of the feed had been reached. The purpose of these tests was to provide information on filtrate flux and quality as a function of the type of tube and the operating conditions used.

The thirteen tests, together with operating conditions and flux results, are summarized in Table 3.

PHASE I SINGLE-TUBE FLUX RESULTS

Test No. G-1 (Figure 8)

The initial test was with a 6-mm nylon tube. Pressure was 0.35 kg/cm² (5 psi); velocity 2.13 m/s (7 ft/sec) and flow was 3.8 lpm (1 gpm). The initial flux was well over 36,600 lmd (900 gfd) (at 35°C) and the flux declined to a plateau of value of over 2400 lmd (600 gfd) after 20 hours, and 20,000 lmd (500 gfd) after 90 hours of testing. The limed feed was a very turbid, tan color, while the permeate was clear. Samples of the feed and permeate were collected and sent to General Battery Corporation for analyses. The flux results are presented in Figure 8.

Test No. G-2 (Figure 9)

This test also was with a 6-mm nylon tube. Pressure was 0.35 kg/cm² (5 psi). However, the velocity was reduced to 1.22 m/s (4 ft/sec) in the interests of possible energy savings. Flow was 2.08 lpm (0.55 gpm). The inital flux was well over 2400 lmd (600 gfd) but declined to a plateau value of 2000 lmd (500 gfd) after 10 hours of testing, continuing at this level up to 46 hours. At that point, the tube was cleaned with a "Servac" solution 2.6 ml/l (10 ml/gal) after which the flux increased to over 45,000 lmd (1100 gfd). The filtration continued over a weekend period with the flux appearing to level off at over 8100 lmd (200 gfd) after 115 hours of testing! The feed was again of a dense, tan texture, with the permeate completely clear. Samples of the feed and permeate were collected and sent to General Battery Corporation for analyses. The flux results are presented in Figure 9.

Test No. G-3 (Figure 10)

This test was conducted with a 6-mm ID nylon tube. A velocity of 1.22 m/s (4 ft/sec) and a pressure of 0.35 kg/cm² (5 psi) were used. The wastewater pH was adjusted to 9.9 by lime addition over a period of 3 hours prior to initiation of filtration. The initial flux was over 41,000 lmd (1000 gfd) and it reached a near-plateau value of 9900 lmd (243 gfd) after 43 hours of testing. At that point the tube was cleaned with Servac solution 2.6 ml/l (10 ml/gal) for 15 minutes. The cleaning restored the flux to 40,000 lmd (984 gfd), and at 75 hours the flux was still in excess of 2400 lmd (600 gfd).

Test No. G-4 (Figure 11)

A 6-mm ID nylon tube with a broad pore-size distribution was investigated in this test at an operating pH of 7.9.

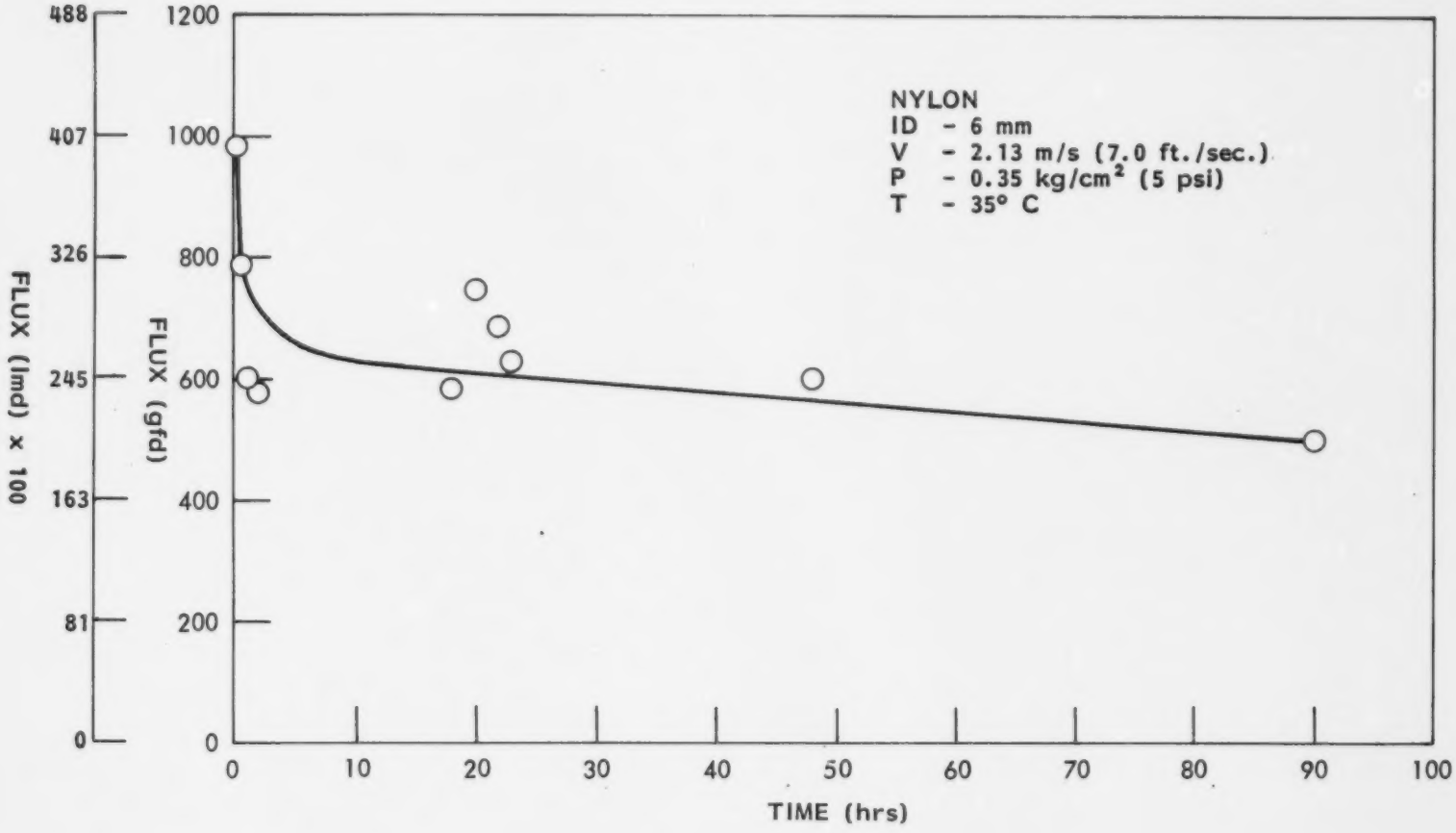

Figure 8. Test G-1 - Permeate flux test results.

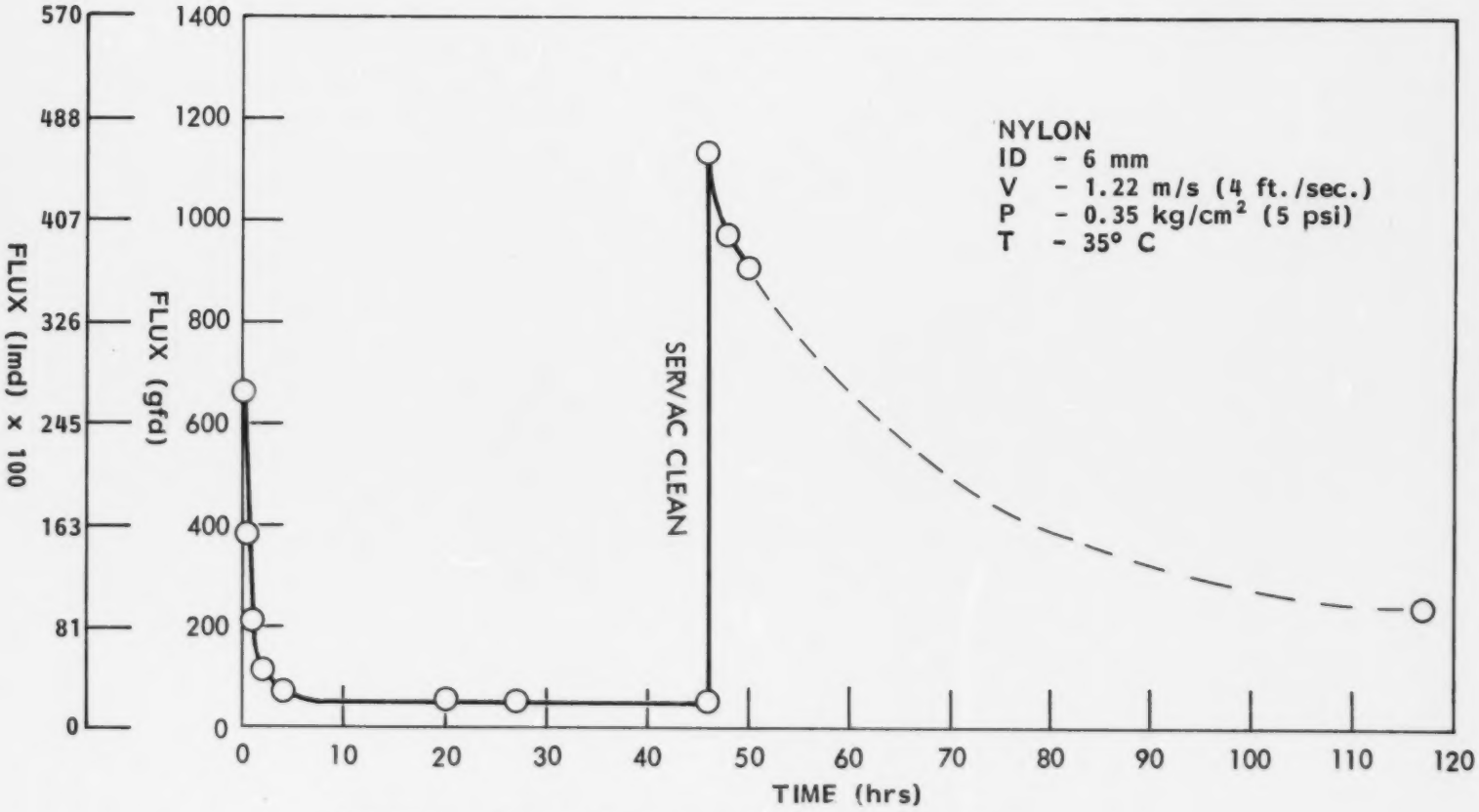

Figure 9. Test G-2 - Permeate flux test results.

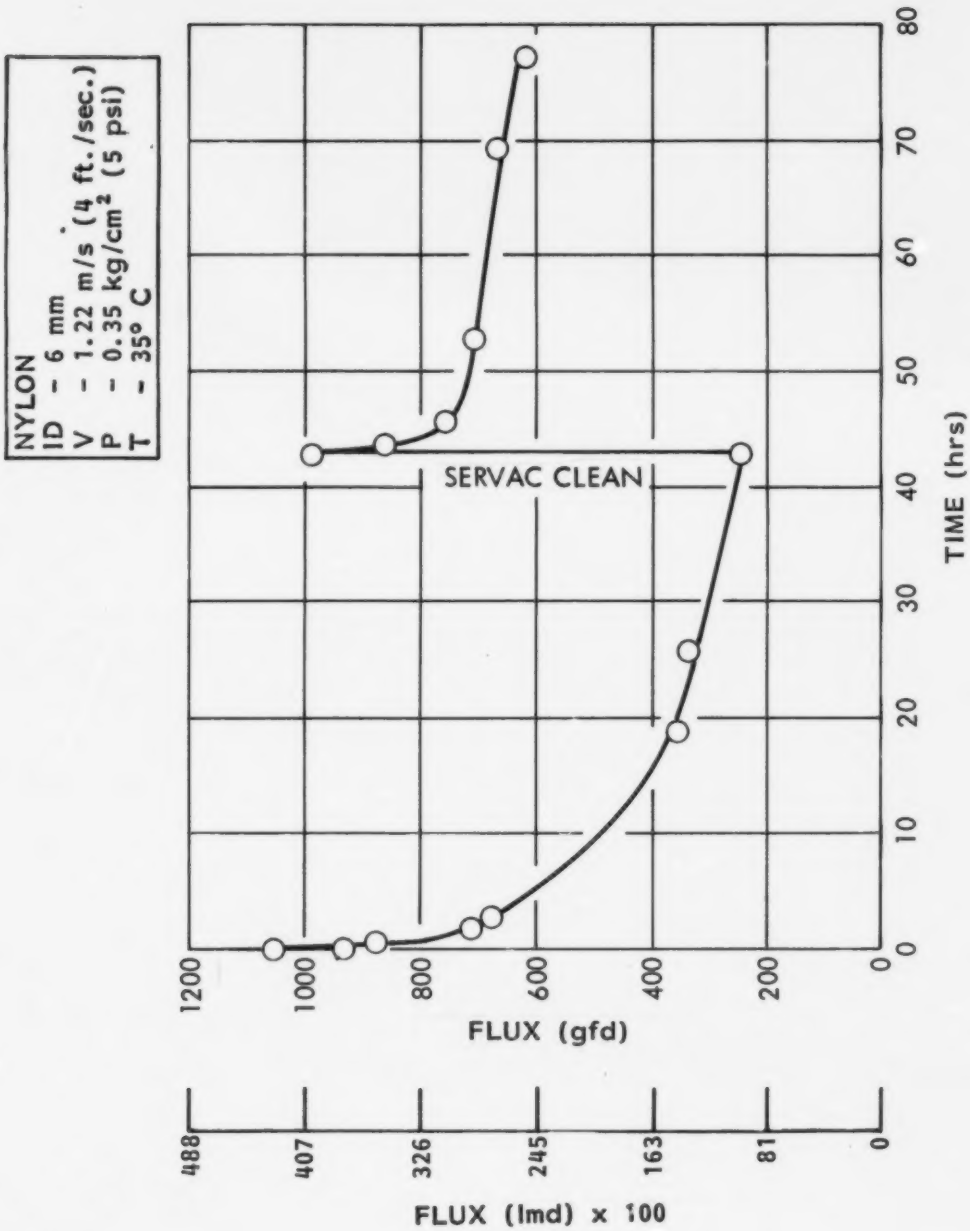

Figure 10. Test G-3 - Permeate flux test results.

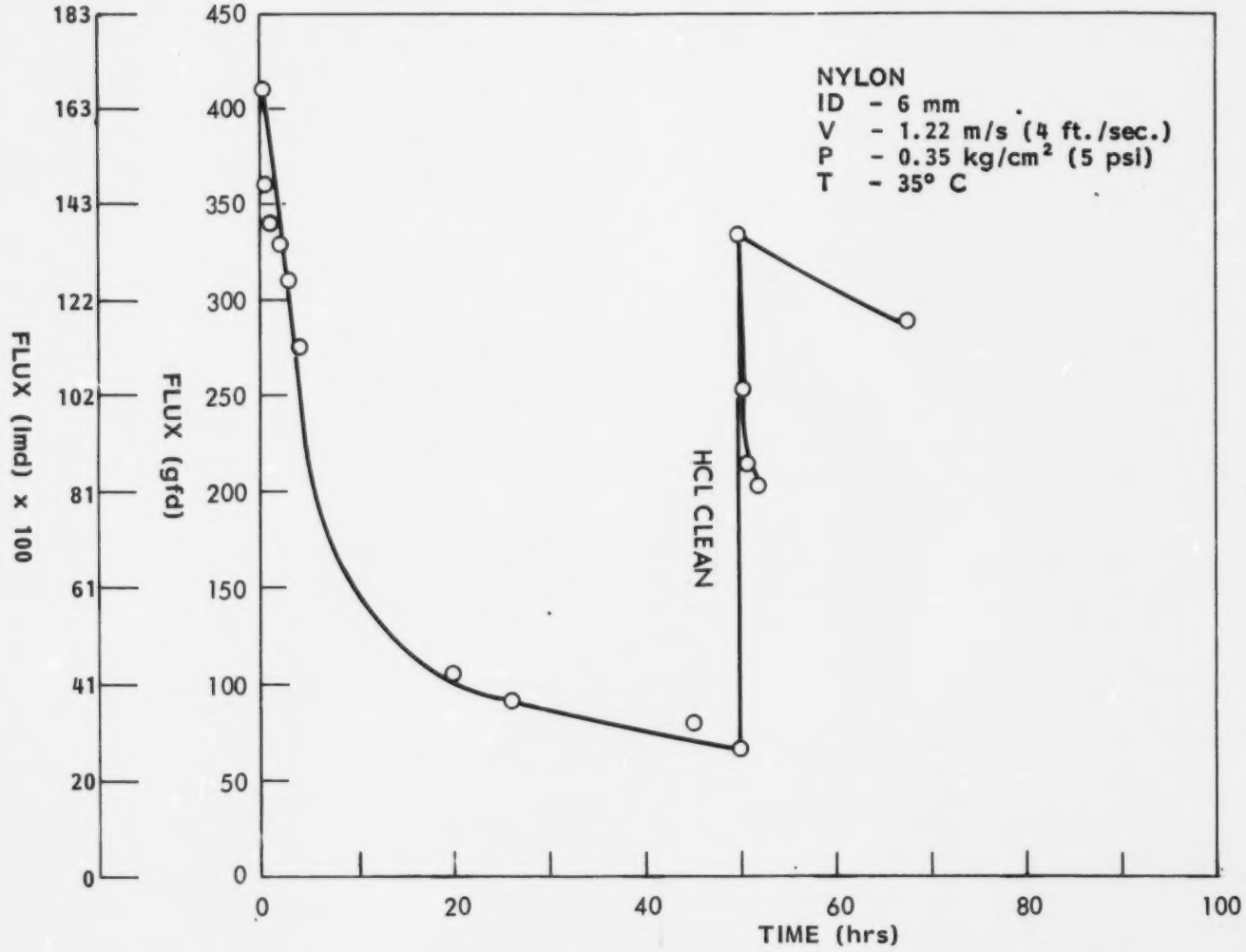

Figure 11. Test G-4 - Permeate flux test results.

Pressure and velocity were the same as in Test No. G-3. The initial flux of 16,700 lmd (411 gfd) declined to 2700 lmd (67gfd) in 54 hours of testing. The tube was cleaned at that point with a solution of HCℓ (100 ml HCℓ/liter H_2O) for 10 minutes. The cleaning restored the flux almost to its original value (about 13,600 lmd (334 gfd)), indicating effective cleaning of solids not only from the wall of the tube, but also from within the wall itself. The HCℓ cleaning method was very promising. The flux then declined to 8100 lmd (200 gfd). Subsequently, a dramatic flux increase occurred which is not readily explained, with the flux rising to 11,800 lmd (290 gfd).

Test No. G-5 (Figure 12)

A 6-mm ID high-density polyethylene (HDP) tube was used to obtain data for flux comparisons with nylon. An operating pH of 9.8 at 0.35 kg/cm² (5 psi) and a 1.22 m/s (4 ft/sec) velocity were used in this test. The initial flux of 15,000 lmd (369 gfd) declined to 200 lmd (5.1 gfd) after 46 hours of operation, indicating the inferiority of this polyethylene tube when compared with nylon for the present application. Future tests were then limited to nylon tubes only.

Test No. G-6 (Figure 13)

A 9-mm ID nylon tube was utilized in this test at 0.35 kg/cm² (5 psi) pressure and velocity of 1.22 m/s (4 ft/sec), at an operating p H of ~7.8. The starting flux of 23,900 lmd (587 gfd) declined to 2500 lmd (62 gfd) after 92 hours of operation. It is relevant to note in Figure 13 that no real "plateau" value was reached in this test, probably indicating that the velocity is inadequate for the larger 9-mm tubes and that there may be a sludge membrane buildup continuously on the inside walls of the tube, as a result of insufficient turbulence and flow. Later tests with another 9-mm tube at the same velocity with cleaning produced excellent fluxes, however, 9200 lmd (225 gfd) at 160 hours (Test G-11).

Test Nos. G-7 and G-8 (Figure 14)

The purpose of these tests was to obtain deeper insight into the filtration mechanism by comparing the flux of the supernatant (containing very small amounts of suspended solids) with the flux of the high-SS containing wastewater. Both tests used a 6-mm nylon tube at 0.35 kg/cm² (5 psi) and 2.13 m/s (7 ft/sec). The flux results indicated that in this case the presence of suspended solids had little effect on flux. For example, in Test G-7 with the supernatant alone, the flux was 500 lmd (124 gfd) at 1 hour, compared with 5100 lmd (125 gfd) in Test G-8 in which $CaSO_4$ has been added to the supernatant.

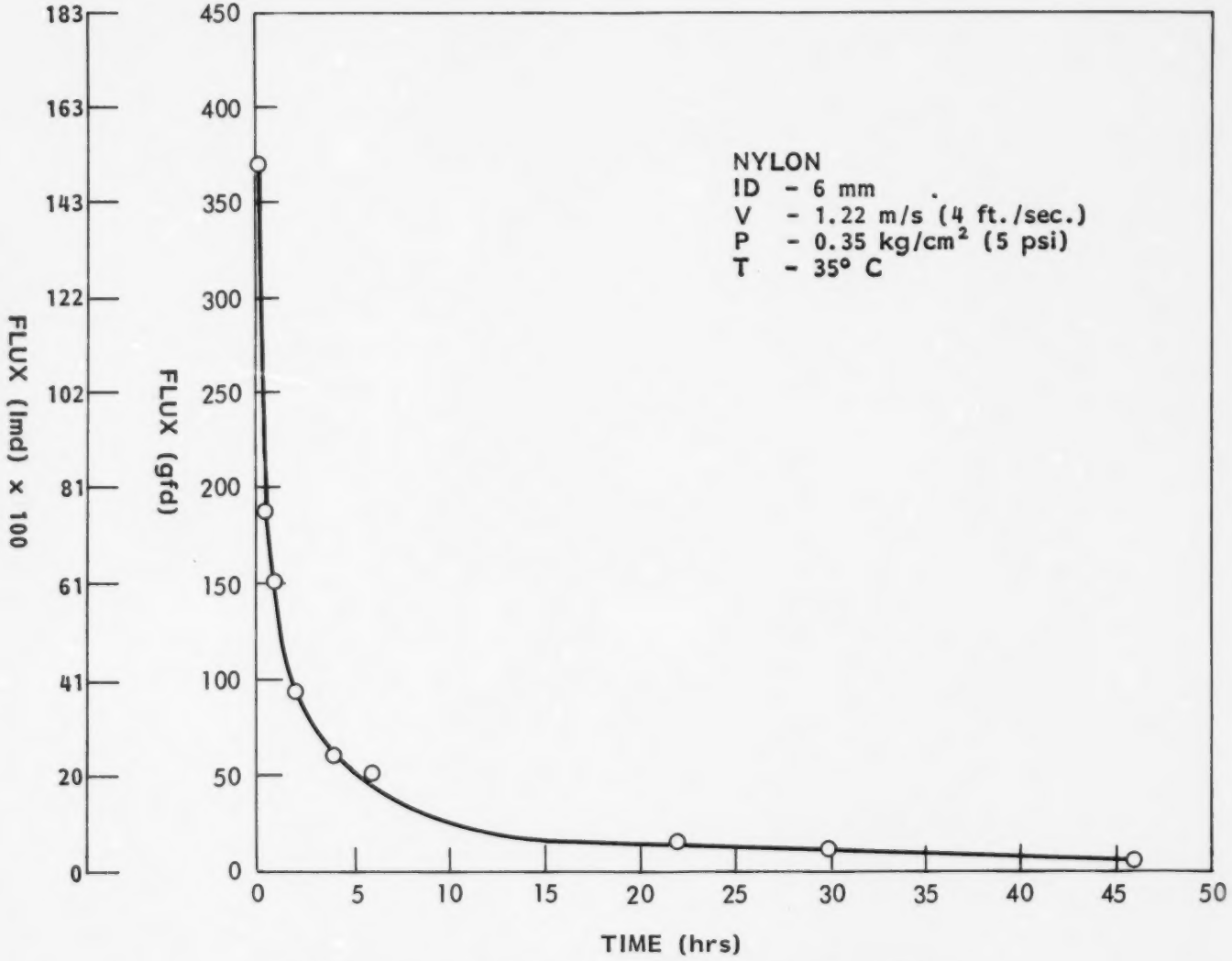

Figure 12. Test G-5 - Permeate flux test results.

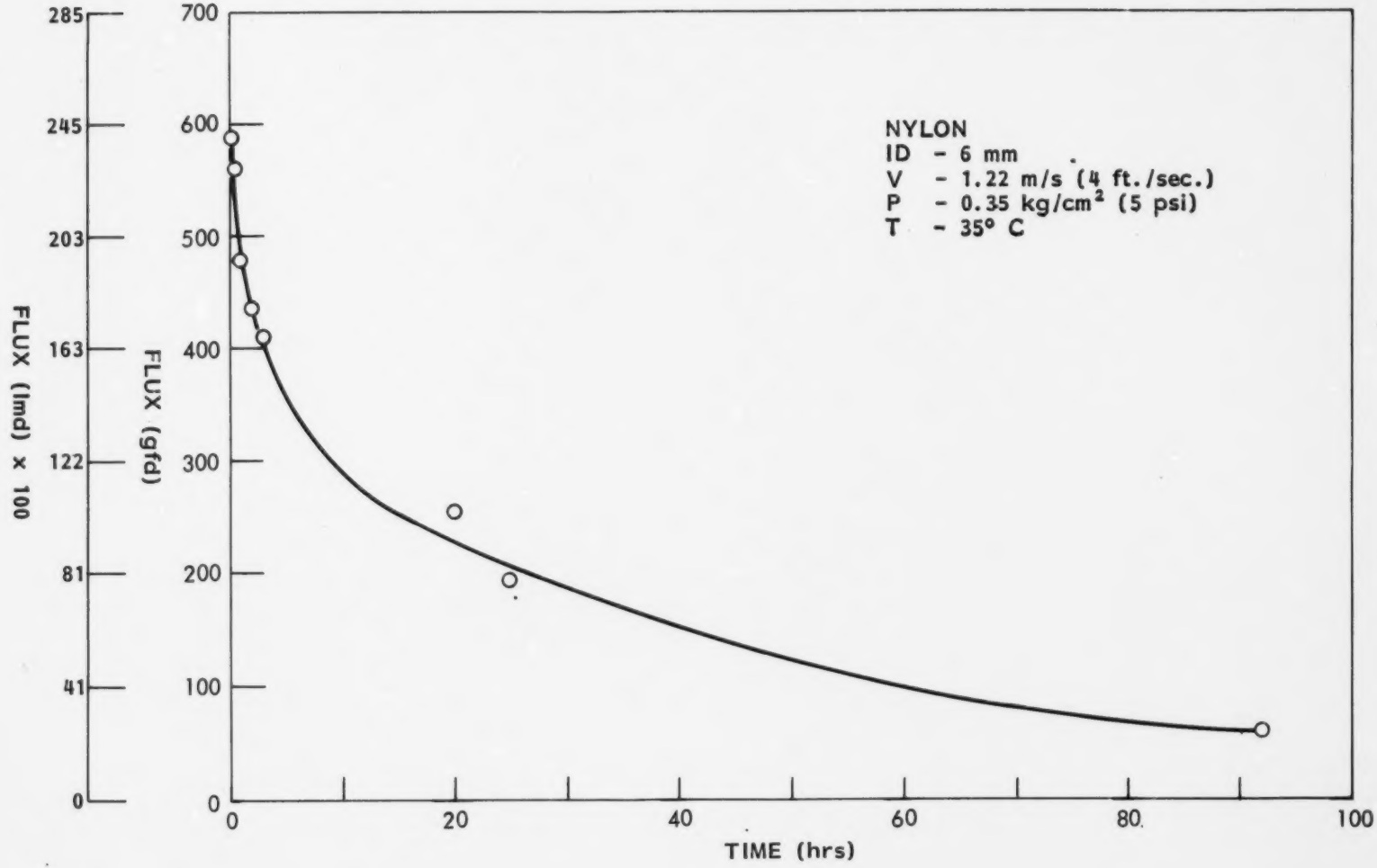

Figure 13. Test G-6 - Permeate flux test results.

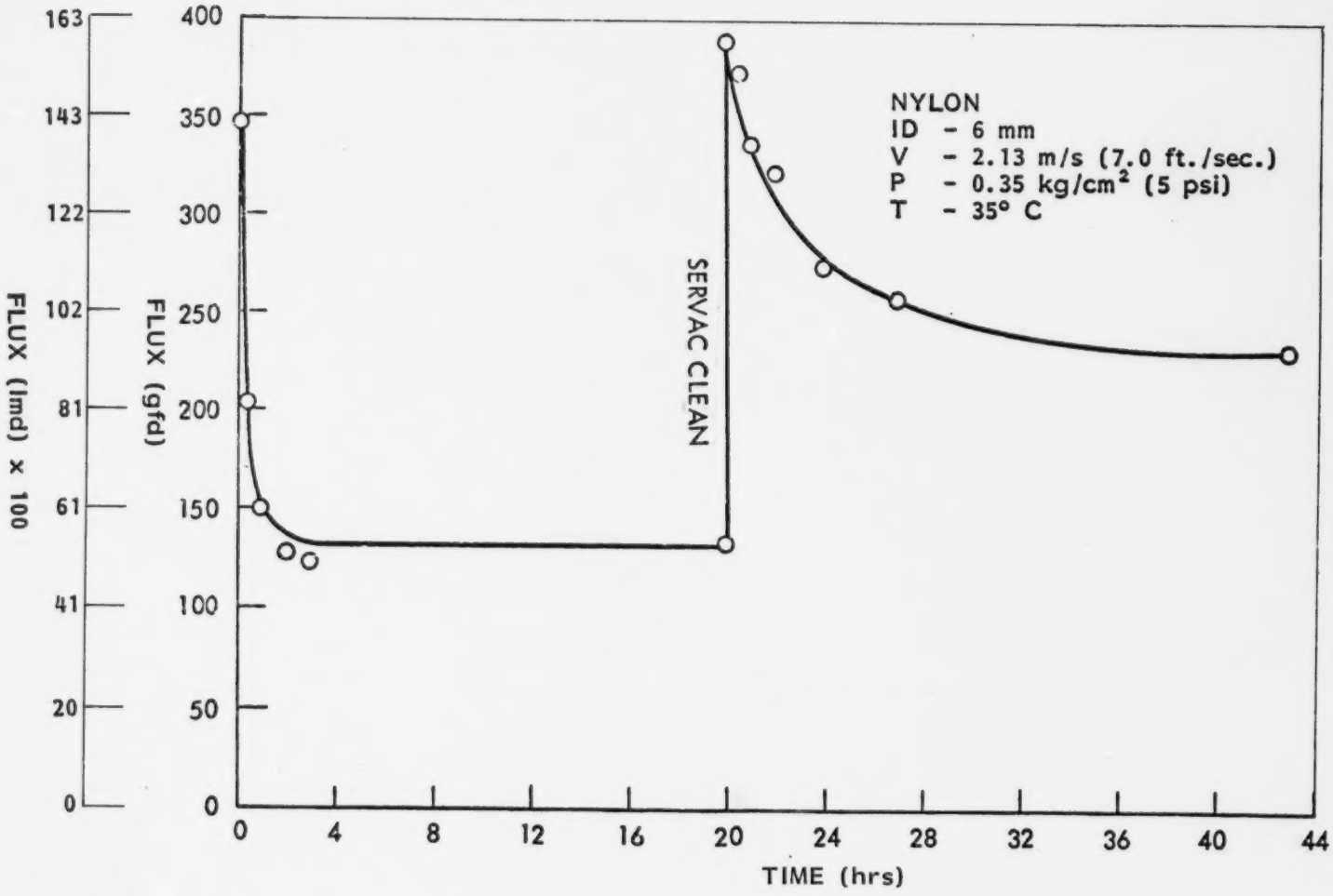

Figure 14. Test G-8 - Permeate flux test results.

Test No. G-9 (Figure 15)

This test was designed to evaluate the effect of concentration on filtration performance. The wastewater (at pH = 10) was concentrated during the day and recycled (in a constant-concentration mode) during the night. A 4-mm ID nylon tube was used at a velocity of 2.13 m/s (7 ft/sec) and 0.35 kg/cm (5 psi) pressure). A total of 96 liters (25.5 gal) of permeate (including 6.4 liters (1.7 gal) of evaporation losses) were removed from the starting volume of 110 liters (29 gal), yielding 87.9% removal efficiency. The test demonstrated that the continuously increasing solid concentration in the feed had no marked adverse effect on the fluxes (at the end of the test the flux was still 6100 lmd (150 gfd)).

Test No. G-9A

Further concentration of the concentrate produced in Test G-9 was not possible in the same test loop because of a lack of the necessary volume for positive pump suction. Therefore, 1300 ml of the concentrate from Test G-9 were transferred to a small fitration loop for further treatment. Using the same tube and the same operating conditions, a further concentration of 35.9% was achieved, with a final flux of 6700 lmd (164.5 gfd). At this point, the sludge was too thick to pump.

Test No. G-10 (Figure 16)

The purpose of this test was to evaluate the significance of adding a flocculant to the feed to enhance particle agglomeration and filtration performance. In this test, a 6-mm nylon tube was used at 0.35 kg/cm^2 (5 psi) and a velocity of 1.22 m/s (4 ft/sec), at a pH of ~9.2. The flocculant used was Drewfloc 2270 in a concentration of 15 ppm. The initial flux of over 50,900 lmd (1250 gfd) dropped to a very respectable level of 15,500 lmd (382 gfd) after 31 hours of operation, plateauing at 11,800 lmd (290 gfd) after 72 hours. This single test does not necessarily demonstrate that the use of flocculants is essential, since other tests without flocculant also had high flux results (i.e., G-1 with a flux of 19,900 lmd (490 gfd) at 90 hours and G-11 with a flux of 9200 lmd (225 gfd) at 160 hours).

Test No. G-11 (Figure 17)

This was the second 9-mm nylon tube test, and it was conducted to obtain additional statistical data on 9-mm tube performance. The operating conditions were the same as the first 9-mm nylon tube (Test G-6), i.e., 0.35 kg/cm^2 (5 psi) and 1.22 m/s (4 ft/sec). The initial flux of 23,000 lmd (564 gfd) dropped

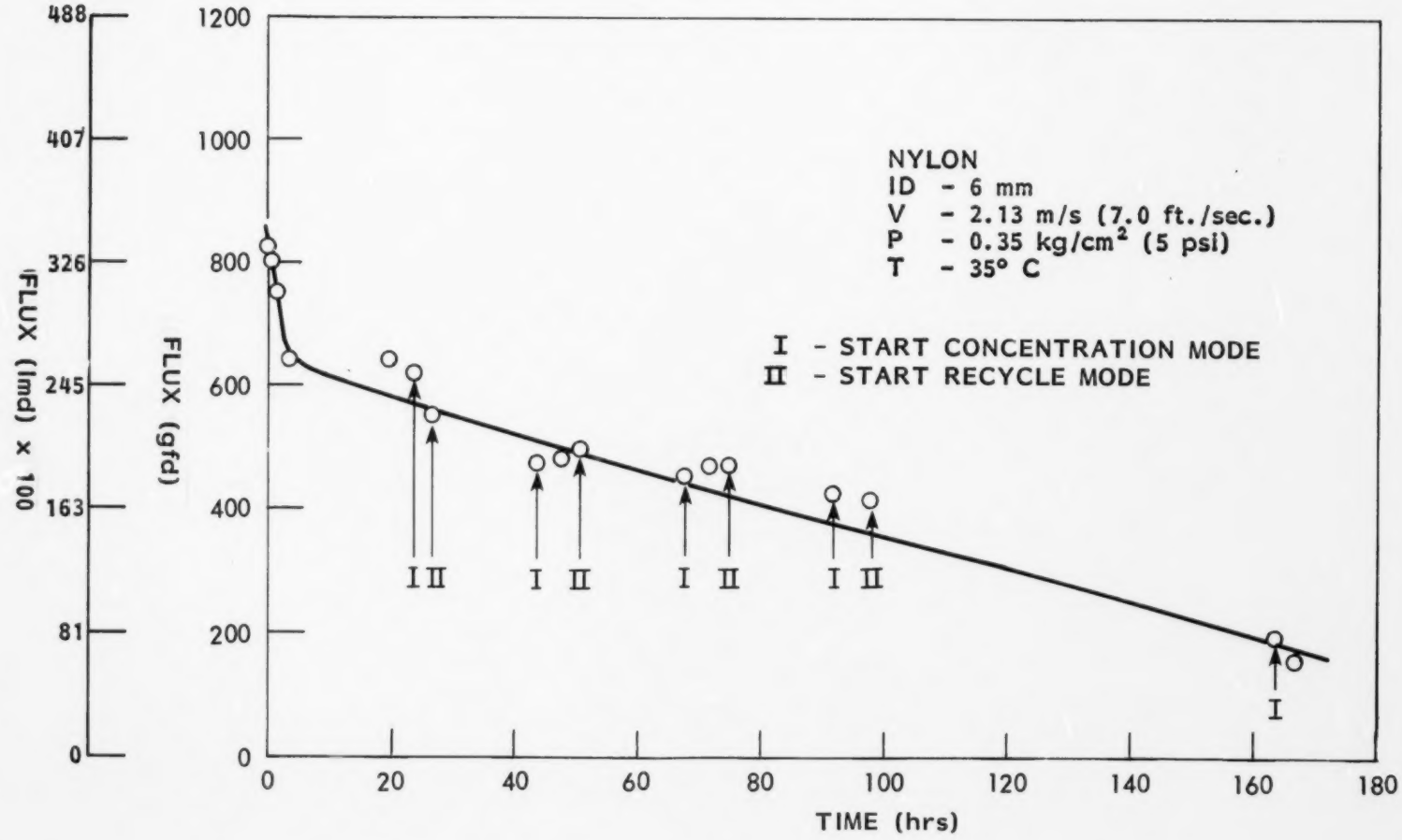

Figure 15. Test G-9 - Permeate flux test results.

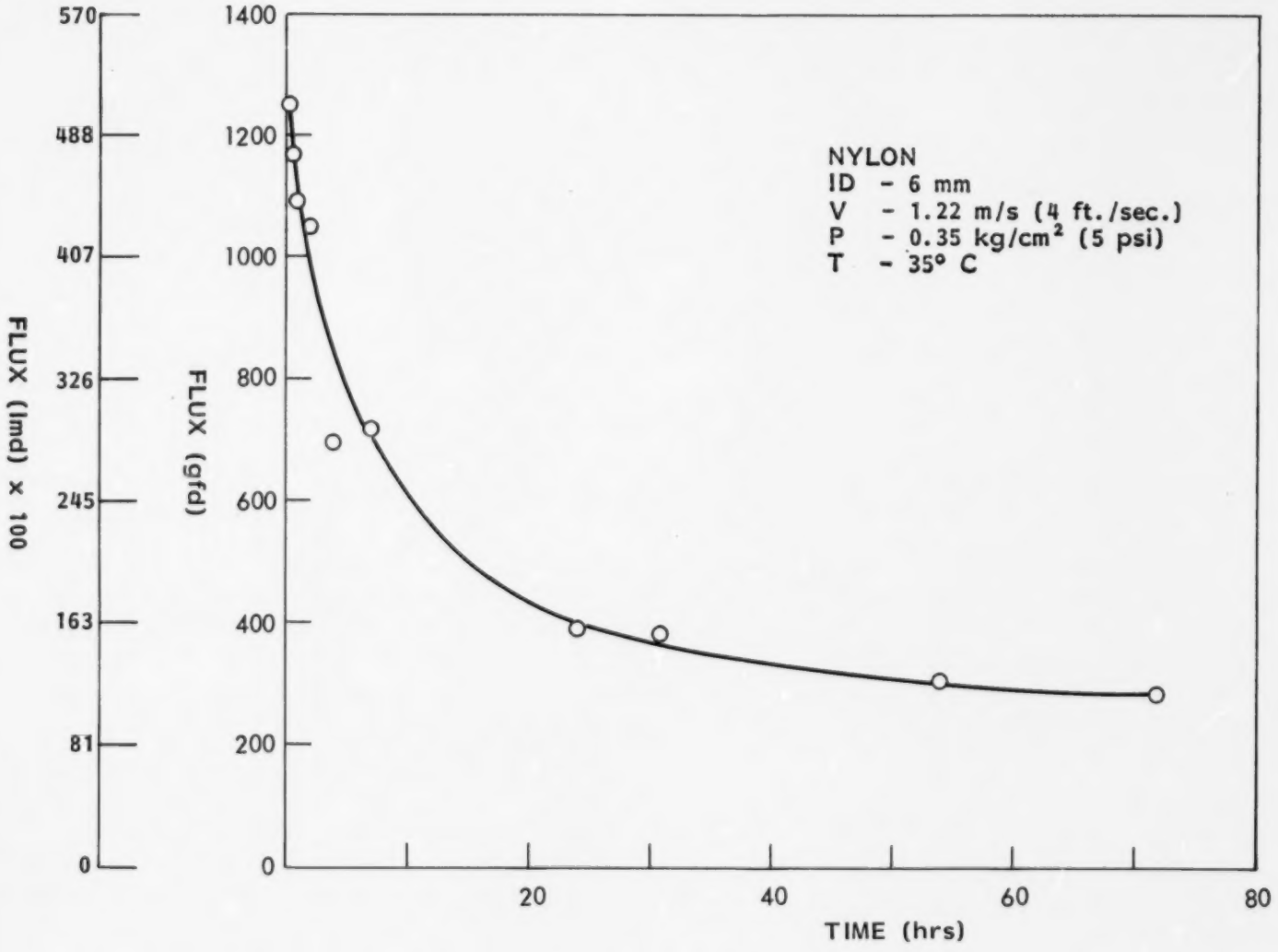

Figure 16. Test G-10 - Permeate flux test results.

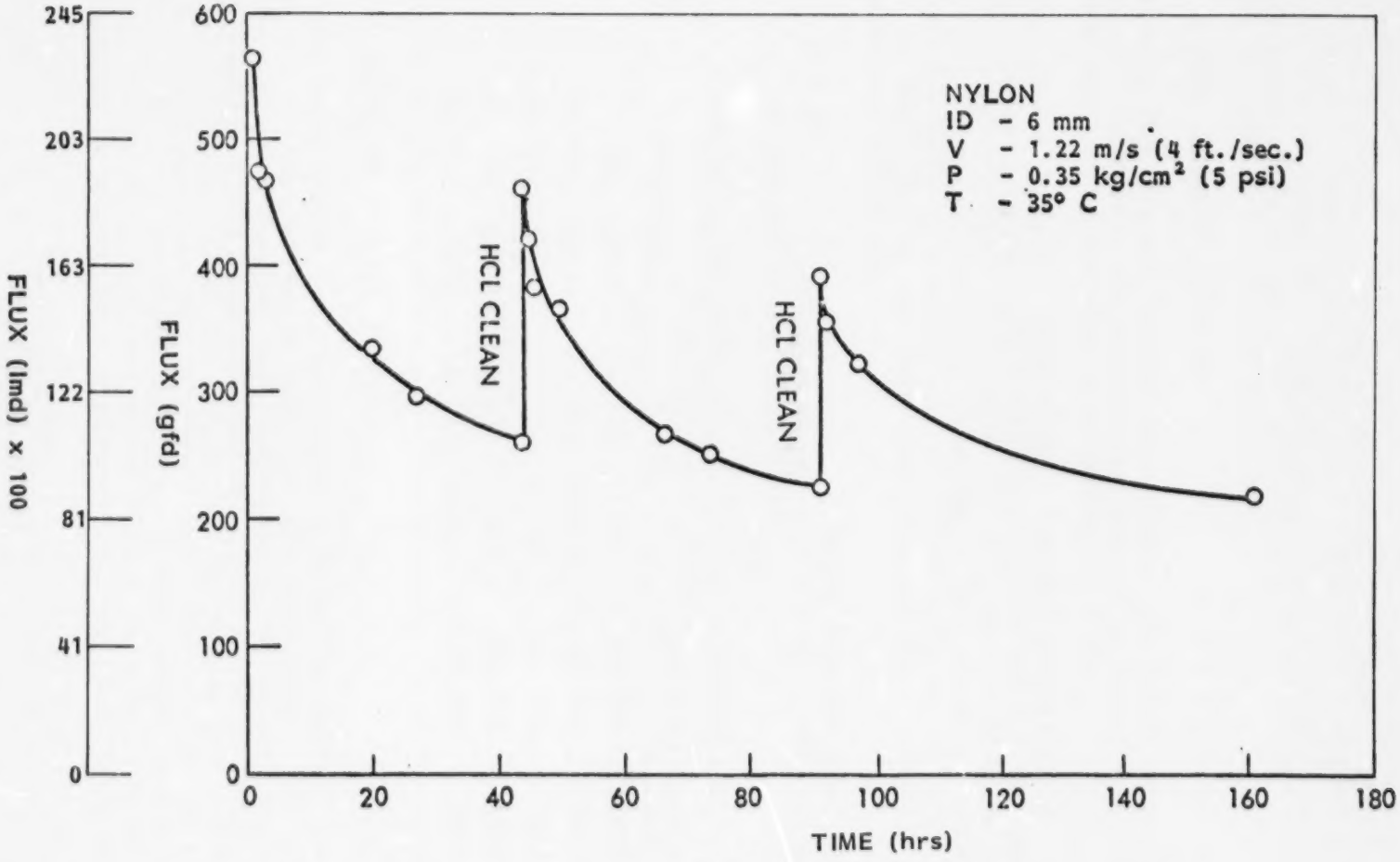

Figure 17. Test G-11 - Permeate flux test results.

to 10,600 lmd (260 gfd) after 44 hours. At that point, the tube was cleaned with dilute HCℓ, whereupon the flux returned to 18,800 lmd (461 gfd). After an additional 47 hours, the flux was starting to plateau at 9200 lmd (225 gfd). A second cleaning with HCℓ returned the flux to 15,900 lmd (391 gfd) with a plateau level of 8800 lmd (217 gfd) having been reached after a total of some 161 hours of operation.

PHASE I TUBE CLEANING RESULTS

During the Phase I single-tube tests, the tubes were cleaned at periodic intervals to investigate the effectiveness of various cleaning procedures for the restoration of flux.

Two cleaning agents were used. One was a commercial detergent, Servac, containing a mild phosphoric acid. The second was dilute HCℓ (2-3%). Figures 9, 10, 11, 14 and 17 show the flux regeneration achieved by cleaning. This cleaning is accomplished simply by pumping the cleaning solution through the inside of the tubes in the same direction as the feed flow for approximately 15-30 minutes.

It can be seen by examination of these figures that flux can readily be restored to approximately its original value, as summarized in the following table:

TABLE 4. RESTORATION OF FLUX BY CLEANING

Test No.	Flux Value lmd (gfd) Original		Final		After Cleaning	
G-2	2,400	(600)	4,100	(100)	48,800	(1200)
G-3	32,600	(800)	12,200	(300)	40,000	(1000)
G-4	16,300	(400)	3,100	(75)	14,200	(350)
G-8	14,200	(350)	5,700	(140)	16,300	(400)
G-11	22,400	(550)	12,200	(300)	16,300	(400)

PHASE I PERMEATE QUALITY RESULTS

Tube performance must be judged, basically, upon three parameters: flux, permeate quality, and economics. The previous paragraph presented the flux results, which are excellent. This paragraph deals with permeate quality, which is summarized for lead in Table 5, and for all metals in Tables 6-A and 6-B. Both feed and permeate were analyzed for: TS, SS, Pb, Cu, Zn, Ni, Sb and As. It appears that, over a wide range of operating pH, from 7.6 to 10.4, precipitation varies in effectiveness, for example, Pb values in the permeate varied from <0.01 to

TABLE 5. PHASE I TEST RESULTS-PERMEATE QUALITY OF LEAD-ACID BATTERY MANUFACTURE WASTEWATERS

Test No.	pH Range	Pb in Permeate
G-1	7.6 - 10.4	0.08 - 0.36
G-2	9.2 - 9.8	0.06 - 0.09
G-3	9.2 - 9.6	0.06 - 0.11
G-4	7.5 - 7.9	0.09 - 0.16
G-5	9.0 - 9.7	0.09 - 0.09
G-6	7.7 - 7.8	<0.01 - 0.03
G-7	Supernatant—No Analyses Made Tests Conducted Only For Flux Data	
G-8		
G-9	9.1 - 10.1	0.07 - 0.01
G-10	7.25 - 9.36	0.04 - 0.09
G-11	11.63 - 11.75	0.06 - 0.17

TABLE 6-A. NEUTRALIZED BATTERY FEED AND FILTRATE ANALYSIS TYPICAL SINGLE-TUBE TEST RESULTS

	TS (mg/ℓ)	SS (mg/ℓ)	Pb (mg/ℓ)	Cu (mg/ℓ)	Zn (mg/ℓ)	Ni (mg/ℓ)	Sb (mg/ℓ)	As (mg/ℓ)
FEED	50,312	43,762	8.55	1.74	2.56	1.85	0.57	0.027
FILTRATE	2,889	5	0.059	0.027	<0.001	0.0028	0.35	<0.002
% REMOVAL	94.26	99.99	99.31	98.45	99.96	99.84	38.6	92.59

TABLE 6-B. GENERAL BATTERY-HYDROPERM DEMONSTRATION PROGRAM PHASE I LABORATORY ANALYSES

Test No.	Sample No.	Condition	Test Time (Hrs.)	Lead Pb (mg/ℓ)	Copper Cu (mg/ℓ)	Nickel Ni (mg/ℓ)	Zinc Zn (mg/ℓ)	Arsenic As (mg/ℓ)	Antimony Sb (mg/ℓ)	Iron Fe (mg/ℓ)	pH	Total Solids (mg/ℓ)	Suspended Solids (mg/ℓ)
G-1	1	As Received	-	21.1	0.52	0.23	0.69	0.027	1.56	-	1.1	1,928	217
	2	After Neutralization	-	226.0	1.39	0.93	2.87	0.023	1.51	-	8.2	33,137	26,948
	3	Permeate	1.00	0.36	0.086	0.042	0.007	<0.002	<0.10	-	9.9	2,896	10
	4	Permeate	18.00	0.079	0.088	0.016	0.002	<0.002	<0.10	-	10.4	2,905	8
	6	Feed	18.50	198.6	1.05	1.16	2.87	0.027	1.47	-	10.9	31,847	19,648
	8	Permeate	22.25	0.70	0.11	0.042	0.012	<0.002	<0.10	-	10.9	2,871	71
	10	Feed	90.00	16.5	0.29	0.032	0.29	0.009	0.18	-	7.9	3,870	993
	12	Permeate	90.00	0.16	0.13	0.042	0.037	<0.002	<0.10	-	7.6	2,544	15
G-2	16	As Received	-	9.52	0.70	0.20	0.50	0.028	1.22	-	1.1	1,509	21
	17	After Neutralization	-	2.52	0.51	0.097	0.23	0.031	0.68	-	8.3	45,757	41,648
	18	Permeate	1.25	0.066	0.053	0.032	0.020	<0.002	0.18	-	9.8	3,228	0
	19	Feed	1.75	4.38	1.04	0.12	0.37	0.029	0.84	-	9.5	39,863	36,123
	20	Feed	20.50	6.58	1.51	2.08	2.05	0.031	0.73	-	9.6	44,524	39,899
	21	Permeate	21.00	0.086	0.033	0.032	0.038	<0.002	0.22	-	9.4	3,140	3
	22	Permeate	25.00	0.066	0.034	0.021	0.030	<0.002	0.26	-	9.4	3,194	5
	23	Feed	44.00	8.55	1.86	1.85	2.87	0.030	0.84	-	9.6	45,110	40,633
	24	Permeate	45.00	0.092	0.036	0.052	0.018	<0.002	0.22	-	9.4	2,965	3
	25	Permeate	48.00	0.059	0.020	0.025	<0.001	<0.002	0.54	-	9.4	2,913	2
	26	Permeate	117.00	0.059	0.027	0.028	<0.001	<0.002	0.35	-	9.4	2,889	5
	27	Feed	117.00	8.55	1.74	1.85	2.50	0.027	0.57	-	9.6	50,312	43,762
G-3	29	Permeate	1.25	0.11	0.054	0.033	0.002	<0.002	<0.10	-	9.4	3,163	10
	31	Permeate	19.25	0.057	0.028	0.033	0.009	<0.002	0.22	-	9.9	2,978	5
	33	Permeate	25.00	0.057	0.027	0.018	0.011	<0.002	0.19	-	9.4	2,949	11
	35	Feed	43.50	11.3	1.72	0.24	0.34	1.88	0.68	-	9.5	45,953	43,768
	37	Permeate	69.00	0.40	0.035	0.051	0.069	<0.002	0.25	-	9.4	2,809	14
G-4	43	Permeate	2.00	0.16	0.032	0.083	0.14	<0.002	0.27	-	7.5	3,469	3
	45	Permeate	21.00	0.11	0.038	0.051	0.15	0.002	0.25	-	7.8	3,386	5
	47	Permeate	26.00	0.086	0.047	0.051	0.14	0.003	0.23	-	7.9	3,377	12
	48	Permeate	46.00	0.11	0.054	0.048	0.13	0.004	0.23	-	7.8	3,248	6
	49	Feed	46.00	4.39	2.03	0.21	0.58	1.95	0.73	-	7.9	44,160	41,770
G-5	51	Permeate	2.50	0.092	0.032	0.045	0.14	<0.002	0.13	-	9.8	3,074	13
	53	Permeate	30.00	0.092	0.047	0.009	0.29	0.002	0.23	-	9.8	2,841	18
	54	Feed	30.00	6.25	1.14	0.30	0.30	1.88	0.52	-	9.8	39,624	37,454
G-6	55	Permeate	1.00	<0.01	0.058	0.11	0.16	0.003	0.25	0.056	8.0	3,383	6
	56	Permeate	20.00	<0.01	0.055	0.083	0.11	0.005	0.27	0.041	7.8	3,309	3
	57	Permeate	25.00	0.029	0.047	0.10	0.11	0.008	0.27	0.041	7.7	3,298	21
	58	Feed	25.00	9.62	1.62	1.67	0.82	0.075	0.92	2.09	7.8	33,764	25,588
	59	Permeate	92.00	0.019	0.088	0.067	0.12	0.008	0.32	0.020	7.7	3,278	2
	60	Feed	92.00	9.62	1.35	-	1.33	0.073	0.68	1.98	7.8	32,158	28,396
G-9	61	Permeate	1.00	-	0.081	0.021	0.067	<0.002	0.11	0.020	10.1	2,302	4
	62	Permeate	20.00	0.093	0.070	0.050	0.043	<0.002	0.21	0.10	10.1	2,565	1
	63	Feed	24.00	13.0	1.88	0.63	0.57	0.075	0.55	0.16	10.1	31,929	6,839
	64	Permeate	27.00	0.10	0.066	0.034	0.036	<0.002	0.23	0.064	10.0	2,555	4
	65	Permeate	51.00	0.074	0.053	0.006	0.040	<0.002	0.29	0.052	9.1	2,553	5
	66	Permeat	75.00	0.10	0.045	0.009	0.047	<0.002	0.34	0.064	9.1	2,574	1
	67	Permeate	98.00	0.093	0.038	0.019	0.045	<0.002	0.37	0.058	7.8	2,646	5
	68	Permeate	167.50	0.083	0.034	<0.005	0.083	<0.002	0.36	0.041	7.8	3,311	2

TABLE 6-B. GENERAL BATTERY-HYDROPERM DEMONSTRATION PROGRAM
PHASE I LABORATORY ANALYSES (CONT'D)

Test No.	Sample No.	Condition	Test Time (Hrs.)	Lead Pb (mg/ℓ)	Copper Cu (mg/ℓ)	Nickel Ni (mg/ℓ)	Zinc Zn (mg/ℓ)	Arsenic As (mg/ℓ)	Antimony Sb (mg/ℓ)	Iron Fe (mg/ℓ)	pH	Total Solids (mg/ℓ)	Suspended Solids (mg/ℓ)
G-10	72	As Received	-	4.03	1.88	0.35	1.13	0.026	1.23	6.96	0.8	937	13
	73	After Neutralization	-	14.81	1.82	<0.005	1.96	0.032	0.332	47.96	8.74	52,514	44,457
	74	Permeate	1.00	0.091	0.052	0.036	0.050	<0.002	0.157	0.031	9.35	2,720	4
	75	Permeate	7.00	0.091	0.033	0.033	0.044	<0.002	0.137	0.031	9.36	2,727	9
	76	Permeate	24.00	0.037	0.035	0.018	0.050	<0.002	0.257	0.031	8.94	2,759	15
	77	Permeate	54.00	0.037	0.035	<0.005	0.054	<0.002	0.275	0.056	7.25	2,756	8
	78	Feed	54.00	23.21	3.51	0.50	1.50	<0.01	0.345	40.82	8.17	51.647	47,087
G-11	79	After Neutralization	-	25.00	2.43	1.00	0.60	<0.01	<0.10	19.39	11.46	63,927	55,141
	80	Permeate	2.00	0.063	0.019	0.020	0.029	<0.002	<0.10	0.026	11.65	2,772	4
	81	Permeate	20.00	0.13	0.019	0.030	0.040	<0.002	<0.10	0.036	11.63	2,908	10
	82	Permeate	44.00	0.13	0.053	0.048	0.041	<0.002	<0.10	0.015	11.68	2,764	5
	83	Feed	44.00	16.07	1.63	2.50	1.60	0.052	<0.10	7.14	11.70	33,448	30,273
	84	Permeate	44.25	0.14	0.12	0.051	0.069	<0.002	<0.10	0.043	11.75	2,817	6
	85	Permeate	91.00	0.13	0.036	0.024	0.057	<0.002	<0.10	0.022	11.70	2,851	6
	86	Feed	91.00	11.54	1.54	1.19	2.98	0.050	<0.10	7.61	11.86	48,080	33,622
	87	Permeate	91.25	0.17	0.13	0.021	0.066	<0.002	<0.10	0.043	11.75	2,873	1
	88	Permeate	161.00	0.067	0.051	0.045	0.032	<0.002	<0.10	0.027	11.70	2,724	6
	89	Feed	161.00	5.77	2.82	0.60	0.96	0.038	<0.10	7.61	11.73	50,131	47,879

0.36. Of significance are Tests G-2, G-3 and G-5, all with operating pH's in the range of 9.0 to 9.8, with lead values in the permeate varying from 0.06 to 0.11. Detailed analytical data are presented in Tables 6-A and 6-B, which show excellent rejection for the other heavy metals as well.

pH ADJUSTMENT

In the test series just described, pH was adjusted from an initial value of the feed of ~1.0 to a value of 8.3 by addition of lime (provided by General Battery Corporation) with continuous stirring over a 3-hour period, prior to initiation of filtration. The range of 8.5 - 9.5 is understood to be optimum for achieving a minimum dissolved lead level. However, without further chemical treatment during the tests, the pH value fluctuated during the filtration tests to levels as high as 10.9 and as low as 7.6. This might be attributable to the introduction of CO_2 into the feed by aeration action of the pump, with the possible subsequent formation of carbonates. The complex nature of the various solubilities of several different metal hydroxides and their interactions, combined with the high affinity of $Pb_2O(OH)_2$ makes precise pH adjustment difficult to achieve.

MODULE TESTS

Description

In these tests, an optimum tube was selected for use in a multi-tube module for both long-term and concentration tests designed to simulate field operation; that is, during the latter stage of this test the filtrate was removed from the feed reservoir. From this test, information was obtained on the long-term filtrate flux and permeate quality of the tube, the degree of concentration of the feed that can be obtained, and the ability to operate without clogging.

Two modules were constructed, one with five tubes and the other with thirteen tubes. The tube selected for these studies was the 6-mm nylon tube shown in Curve I, Figure 3. The modules had an active tube filtration length of 1.8 meters (6 feet). The operational conditions were: circulation velocity of 1.22 m/s (4 ft/sec), pressure of 1.05 kg/cm^2 (15 psi) and pH of about 9.5. The operation pressure was upgraded mainly to simulate the future field installation where about 0.7 kg/cm^2 (10 psi) discharge pressure had to be incorporated.

The module tests began with the "continuous" mode of testing, where the field treatment process is simulated, i.e., as permeate was withdrawn through the module, comparable amounts of newly neutralized acid wastewater were added. Periodically,

sludge was removed from the recirculation tank as would happen in the field operation. This test was conducted for 1000 hours, during which time some forty, 208 liter, (55-gallon) drums of waste acid from General Battery Corporation were neutralized with lime and treated.

Laboratory Setup and Test Procedures

For the module tests, the laboratory setup was modified to add a 378 liter (100-gallon) reaction tank and a 757 liter (200-gallon) sludge thickener/feed recirculation tank (Figure 18). In the first phase of the 1000-hr test, neutralized feed was added to the recirculation tank periodically as the permeate was removed by the modules. The waste acid feed was neutralized in the reaction tank with lime (and stirred), and was pumped periodically to the sludge thickener/feed recirculation tank. As the feed was pumped from the latter tank through the module, the permeate was discarded, and the thickened feed returned to the recirculation tank, at the bottom of which the solids from the feed settled out as sludge. The sludge was also removed periodically to avoid creating a feed too heavy in solids. This, then, represented the continuous field operation as closely as possible.

In the second phase of the 1000-hr test, after having processed some forty, 208 liter (55-gallon) drums of waste acid, the test was allowed to continue in the constant-concentration mode, with permeate returned to the tank, to determine long-term flux.

Module Test Results

The long-term results are shown in Figure 19. As shown in the figure, the initial permeate flux was quite high, at about 2400 lmd (600 gfd). A typical decline of the flux value is shown in this figure. Restoration of the flux is possible only by cleaning which was purposely not done in this test. The final plateau value, after nearly 1000 hours of continuous operation of the module, without cleaning, was still at 8100 lmd (200 gfd)!

The permeate quality of these module studies was just as good as in the single-tube tests. Typical analyical laboratory analyses of the permeate quality are shown in Table 7, at a time when the module was in its 120th hour of operation.

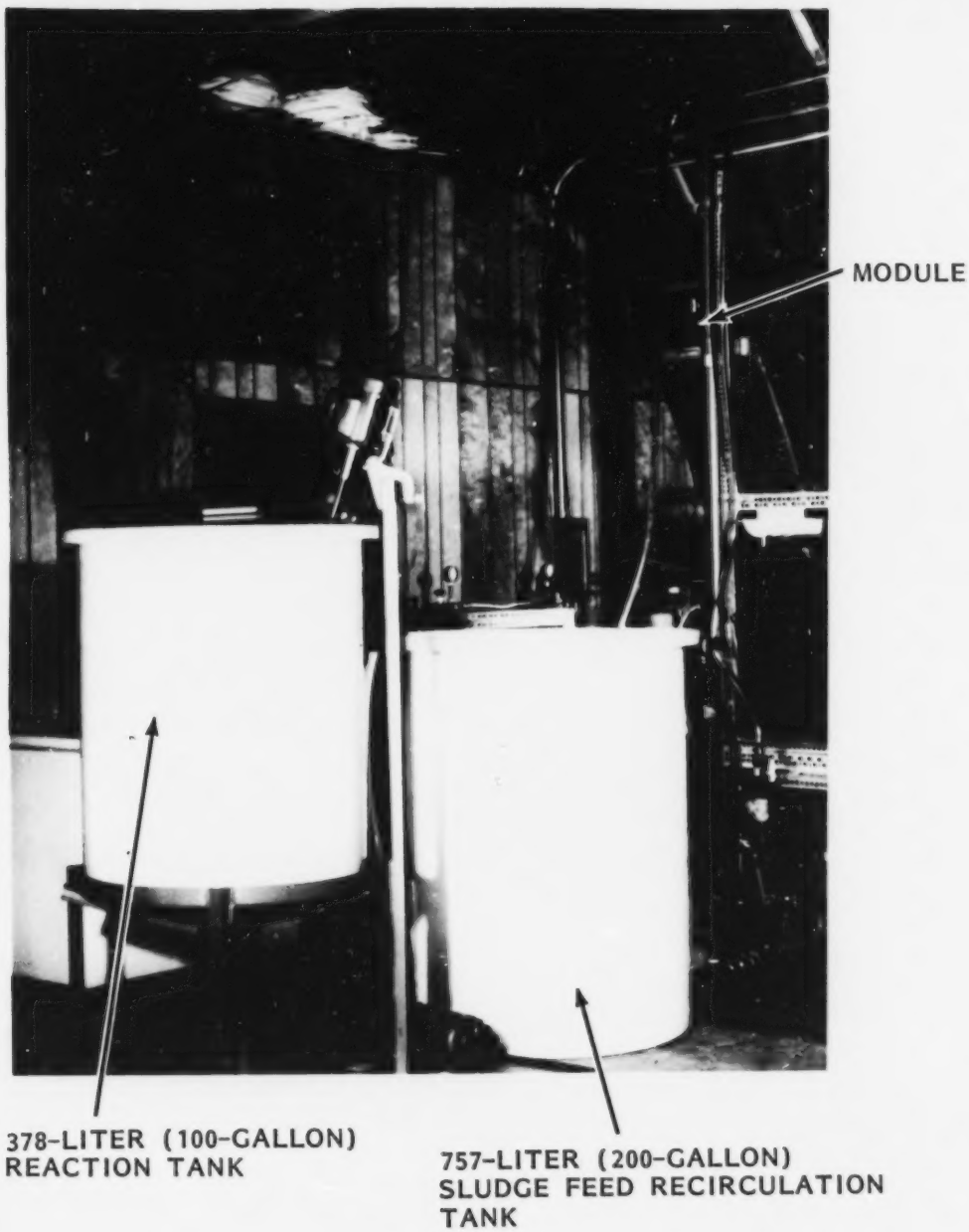

Figure 18. Module test set-up.

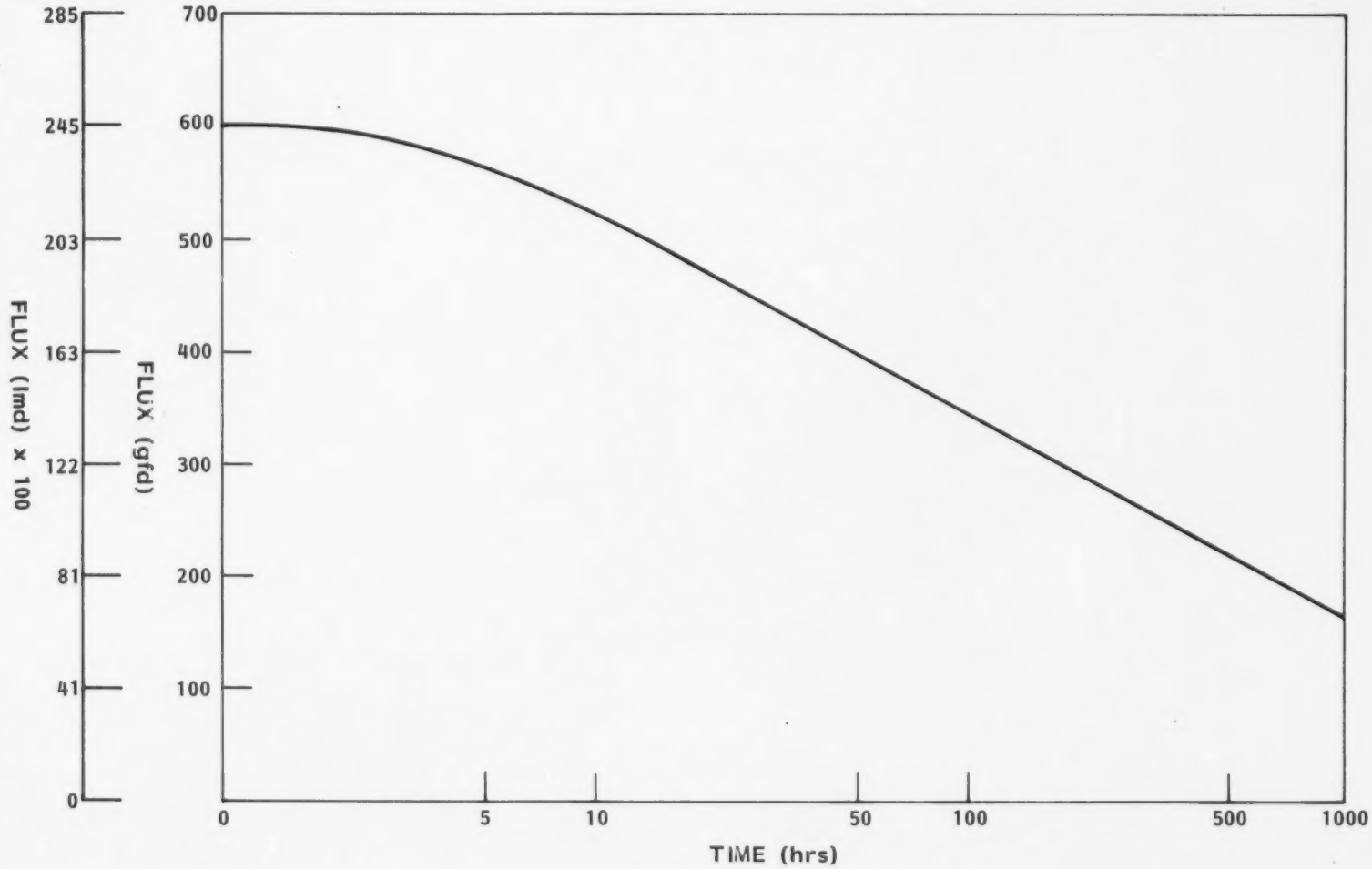

Figure 19. Long-term module test without cleaning.

TABLE 7. MODULE TEST RESULTS NEUTRALIZED BATTERY FEED AND FILTRATE ANALYSIS

	TS (mg/ℓ)	SS (mg/ℓ)	Pb (mg/ℓ)	Cu (mg/ℓ)	Zn (mg/ℓ)	Ni (mg/ℓ)	Sb (mg/ℓ)	As (mg/ℓ)
FEED	24,058	21,054	3.23	0.25	1.16	0.88	0.818	0.054
FILTRATE	2,989	9	<0.01	0.01	0.008	0.058	0.328	<0.002
% REMOVAL	87.58	99.96	99.69	96.00	99.31	93.41	59.90	96.30

Mass Balance Evaluation

A mass balance analysis of the long-term module behavior was also conducted. The basic components used in this analysis were: the total acid wastewater processed; the total permeate removed; the total sludge removed; and the total lime consumed in the neutralization process. The calculations of each component are described below. The discussion of the results follows next.

Total acid wastewater processed: Twenty (20) drums of acid wastewater were used for each of the two module tests: A five-tube, 0.18 m^2 (2 ft^2) module (N19); and a thirteen-tube, 0.28 m^2 (3 ft^2) module (N13). Each drum contained about 208 liters (55 gallons) of wastewater. This amounted to about 4200 liters (1100 gallons) of total wastewater processed in each test.

Total permeate removed: Two methods were used to estimate the total volume of permeate removed during the tests. They were: visual estimation of the wastewater level in the feed tank during the test; and the integration of the area under the flux-time curves. The visual estimation results were taken directly from data sheets prepared by technicians during the tests. The area integration was performed on the flux-time plots with straight lines joining the data points. Because of the nature of the estimation techniques, the two methods did not give exactly the same results. The visual estimation was lower as compared to the integration method. These results are shown in Table 8.

Total sludge removed: the sludge was removed periodically during the tests. The total sludge removal data were taken directly from the data sheet. It should be pointed out that the sludge mentioned here is the sludge that was either pumped, drained, and/or physically bucketed out of the feed tank. The water content in these sludges was not consistent in all cases. Nevertheless, as a first-cut estimate, it was assumed that they were the same, with the solids concentration much greater than

90% by volume.

Total lime consumption: a clear data log simplified the calculation. From the data log, total lime consumed for each test was given in pounds. Since, in the calculation of mass balance, the volume of each component is required, a conversion factor, from weight to volume, for lime was needed. This was estimated by measuring the weight of lime which occupied a certain volume in a graduated cylinder.

With the techniques described above, a summary table was prepared (Table 8). There are two total waste volumes, Line 5 and Line 6. Line 5 is calculated by adding the acid wastewater volume to the lime volume. Line 6 is calculated by adding the permeate volume (the integration method) to the sludge volume. Line 5 can be considered as total mass input to the system while Line 6 indicates the total mass output from the system. Theoretically, they should be the same. Actually, there is about a 2% difference (1 - 1154/1175). This is considered acceptable. Line 7 shows the percent of permeate removal while Line 8 shows the percentage of sludge remaining. This indicates that at least 80% of the total volume was removed from the wastewater as permeate. This means that Hydroperm is a very efficient dewatering process.

ANALYSIS OF FLUX RESULTS (TABLE 3)

Flux Analysis

A representative evaluation of flux performance can be made by examining the plot of filtrate flux versus time in hours as shown in Figure 10. The tube used for this test had an internal diameter of 6-mm and the pore structure was that depicted in Curve I of Figure 3. The operating conditions consisted of a feed pressure of 0.35 kg/cm^2 (5 psi), a feed velocity of 1.22 m/s (4 ft/sec) and a temperature of 35°C. In this constant-concentration test, the filtrate was remixed with the feed. Note from Figure 10 that the flux begins at ~40,700 lmd (~1000 gfd) and declines almost immediately. From this curve and experience with other wastes it was initially estimated that steady "plateau" fluxes of from 6100 to 10,200 lmd (150 to 250 gfd) could be maintained for several days without any tube cleaning. However after 40 hours in the present test, the tube was cleaned by pumping through the tube a solution of Servac (a mild phosphoric acid containing commercial cleaner) in water for a period of 15 minutes. Note from the figure that when the test was started again, the flux had been restored nearly to its original value, 40,700 lmd (1000 gfd), after which it began to decline again. The second flux decline was not as rapid as it was in the first part of the test. This behavior frequently

occurs, probably because of changes in the feed during pumping, and changes in the pore structure of the tube resulting from penetration of fine suspended solids into the pore matrix.

TABLE 8. MASS-BALANCE RESULTS

	N19		N13	
	Liters	(gal)	Liters	(gal)
1. Total Acid Wastewater Processed	4107	(1085)	4164	(1100)
2. Total Permeate Removed				
a) Visual Method	2895	(765)	2952	(780)
b) Integral Method	3459	(914)	3785	(1000)
3. Total Sludge Removed	927	(245)	662	(175)
4. Total Lime Consumed	197	(52)	204	(54)
5. Total Volume Input to the System (1 + 4)	4304	(1137)	4368	(1154)
6. Total Volume Discharge from the System (2b + 3)	4387	(1159)	4447	(1175)
7. Percent of Permeate in Discharge (2b/6)		80%		85%
8. Percent of Sludge in Discharge (3/6)		20%		15%

Pore-Size Distribution

The results for the constant feed concentration tests in terms of filtrate flux (Table 3) demonstrated the influence of several important parameters. The pore structure had a significant influence on flux, since the tube with the wide pore-size distribution (6-26-78-II) had a flux of 10,200 lmd (250 gfd) after 40 hours, while the tube with the narrow distribution (3-22-77-II) had a flux of 2000 lmd (50 gfd) after only 2 hours of operation. For the present waste, it appears that wider pore-size distribution is desirable.

Tube Material

Comparison of Test G-5 with all other tests indicated that nylon was superior to the particular polyethylene tube tested in terms of flux. Nylon tubes were then used throughout the present demonstration program.

Tube Diameter

Excellent fluxes were obtained with 4-mm, 6-mm and 9-mm nylon tubes. For example: 40-hour fluxes of 19,500 lmd (480 gfd) with a 4-mm tube in Test G-9; 40-hour fluxes of 9800, 14,700 and 23,600 lmd (240, 360 and 580 gfd) in Tests G-3, G-10 and G-1 with 6-mm tubes; and 40-hour fluxes of 7100 and 10,600 lmd (175 and 260 gfd) in Tests G-6 and G-11 with 9-mm tubes. Figure 20 shows the fluxes obtained as a function of the filtration time for four different tests: Tests G-3 and G-10 were performed with 6-mm ID tubes while Tests G-6 and G-11 were performed with 9-mm ID tubes. The feed circulation velocity and the operating pressure were kept constant during all these tests. As shown in the figure, during the first few hours of operation (<10 hours) the 6-mm tubes seemed to give fluxes higher than the 9-mm tubes. The difference, however, became less significant with increasing filtration time. In either case, a flux over 8100 lmd (200 gfd) was maintained for 50 hours of continuous operation of all the tubes. Integrated fluxes over the period of an 8-hour shift would be well over 12,200 lmd (300 gfd).

Choice of optimum tube diameter must then be based on considerations other than flux. Since power requirements, pump size and system costs increase rapidly with tube diameter, it was concluded that the 6-mm nylon tube was perferable to the 9-mm. Theoretically, the 4-mm nylon tube would be even more desirable. However, such a small diameter could conceivably result in plugging the entrance of the tube with the rather thick metal hydroxide-calcium sulphate waste. Thus, based upon practical considerations, the 6-mm tube appeared to be determined preferable.

Velocity

Having selected a tube material and size, velocity becomes the final consideration. Adequate velocity is required to maintain turbulent flow and control of the dynamic sludge membrane inside the tube. At the same time, increasing velocity implies increasing power requirements. Based upon the test data presented in Figure 21, it would appear that only modest fluxes can be achieved with a 1.22 m/s (4 ft/sec) velocity. Figure 21 shows that the effect of feed velocity is significant, since

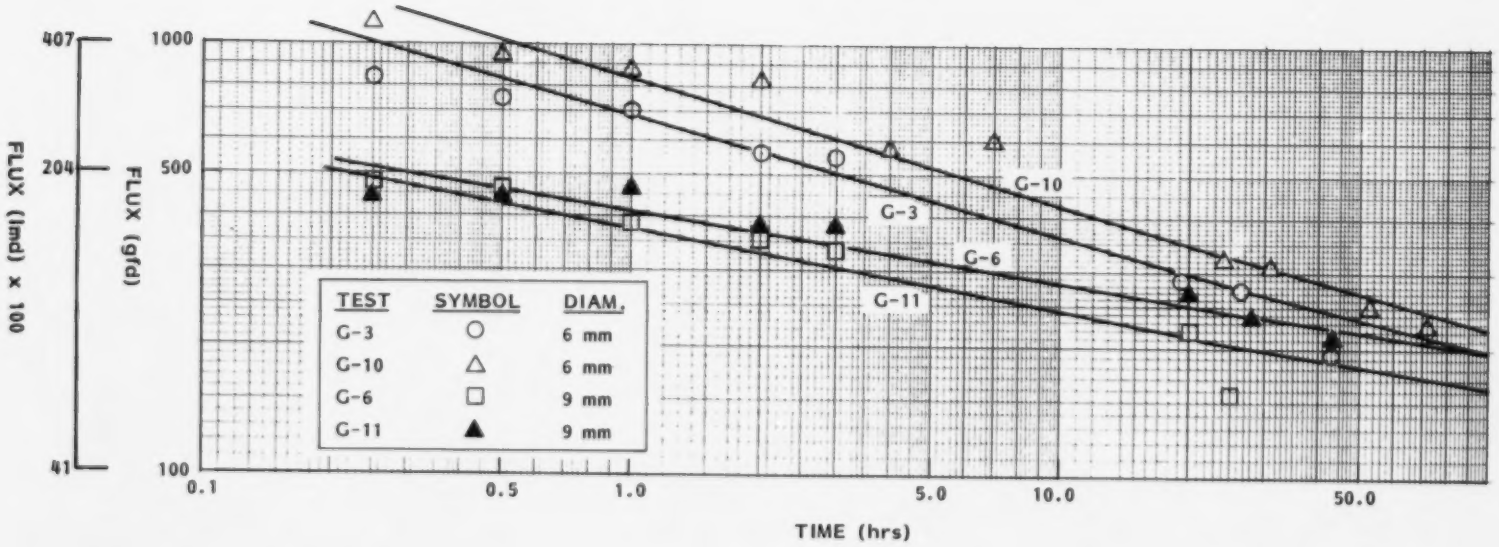

Figure 20. Flux vs. time for identical operating conditions with the General Battery wastes.

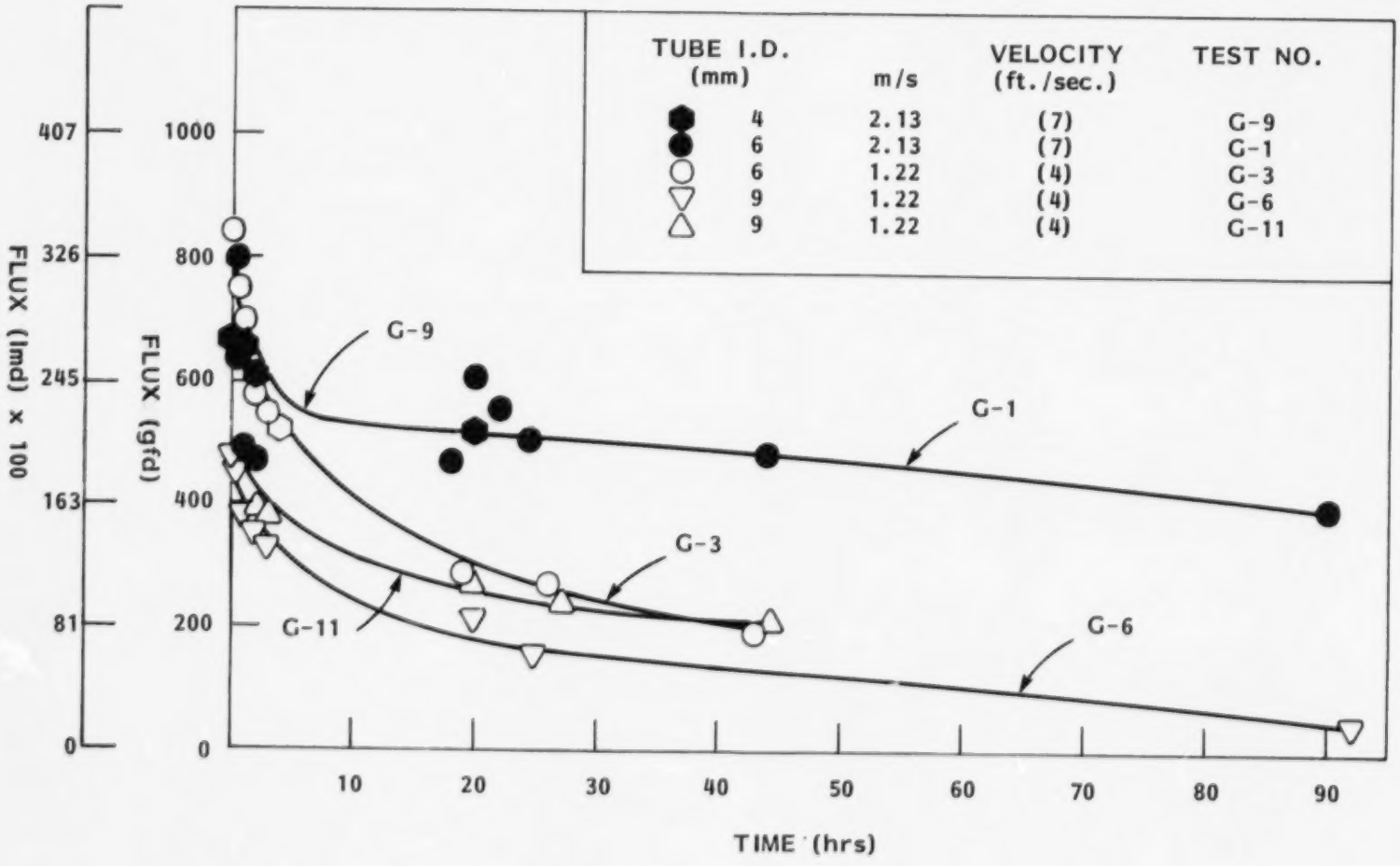

Figure 21. Velocity effects on flux with battery waste.

for the 2.13 m/s (7 ft/sec) tests, the filtrate flux after 40 hours was 8100 lmd (200 gfd) higher than that for the 1.22 m/s (4 ft/sec) tests. Moreover, because of the high suspended solids content of the feed, the Phase II field tests later indicated that a velocity of 2.13 m/s (7 ft/sec) was necessary for proper performance.

Cleaning

Tube cleaning appears to be quite effective both with Servac and dilute HCℓ (see Figure 22). The latter is, however, the cleaning agent of choice, since no additional pollutants are produced. Examination of Figure 22 shows that flux levels after one and two cleanings are still at a very high level for the test duration (50 hours), with flux values at 50 hours 8100 lmd (200 gfd) after cleaning.

Implication of Results

The findings above are consistent with the description of the physics of the filtration process given in Section 3. These results were important for design purposes, since the flux, feed velocity, tube diameters and materials all have an influence on economics in terms of equipment costs and power requirements.

Solids Concentration

The flux record for Test G-9, which was performed with increasing feed concentrations, is shown in Figure 15 (8100 lmd, 200 gfd at 160 hours). The tube type is the same as Tube I shown in Figure 3. However, the internal diameter here is 4-mm. The test conditions are given in Figure 15. Note from the figure that the test was operated in the constant-concentration mode for most of the 160 hours of testing; however, during four 3- to 7-hour intervals, the filtrate was removed from the feed. Thus, the concentration of suspended solids in the feed increased in four steps during the test. During the final part of the test, the total feed volume has been reduced to only 15% of its original value. The flux levels in the figure show that, even with this high feed-solids concentration, fluxes of around 8100 lmd (200 gfd) can be achieved.

In addition to the wastewater treatment studies conducted during these single-tube tests, the sludge dewatering capability of the Hydroperm tubes was also investigated. The conditions for this particular test were: pressure of 1.05 kg/cm² (15 psi), circulation velocity of 1.22 m/s (4 ft/sec); and the tube was 6-mm nylon. The initial waste volume in this test was 121 liters (32 gallons). The test proceeded with permeate being continually removed from the test reservoir. A steady

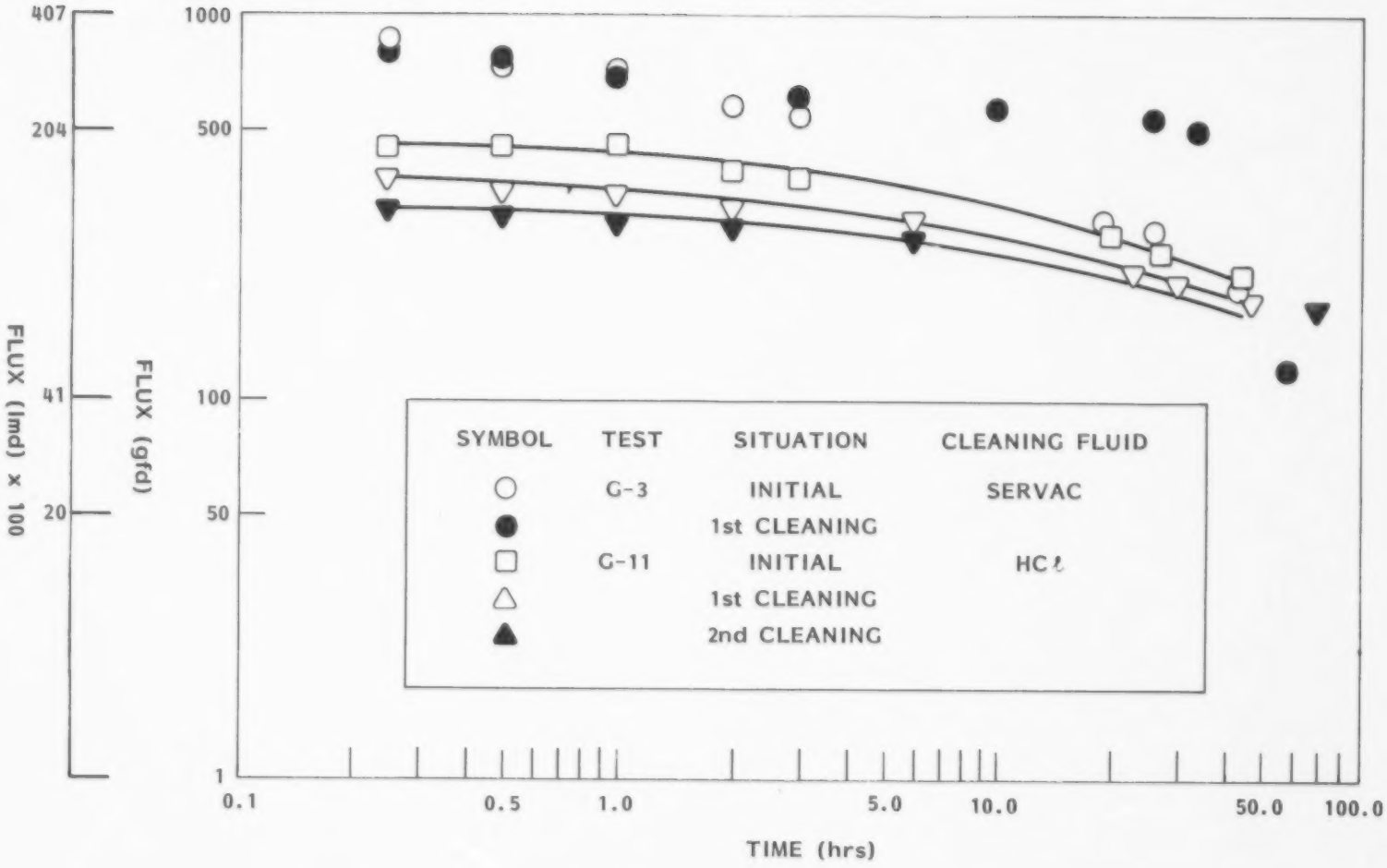

Figure 22. Effect of HCl and Servac cleaning on flux regeneration.

solids concentration buildup (or dewatering process) was thus established. Figure 23 shows the flux decline and solids concentration buildup curves in this test. The initially high fluxes in the range of 28,500 - 32,600 lmd (700 - 800 gfd) decreased to 4070 - 8100 lmd (100 - 200 gfd) as the solids concentration increased to the range of 25% to 35% by weight at the end of this interval. This particular test demonstrated the dewatering capability of the Hydroperm tube.

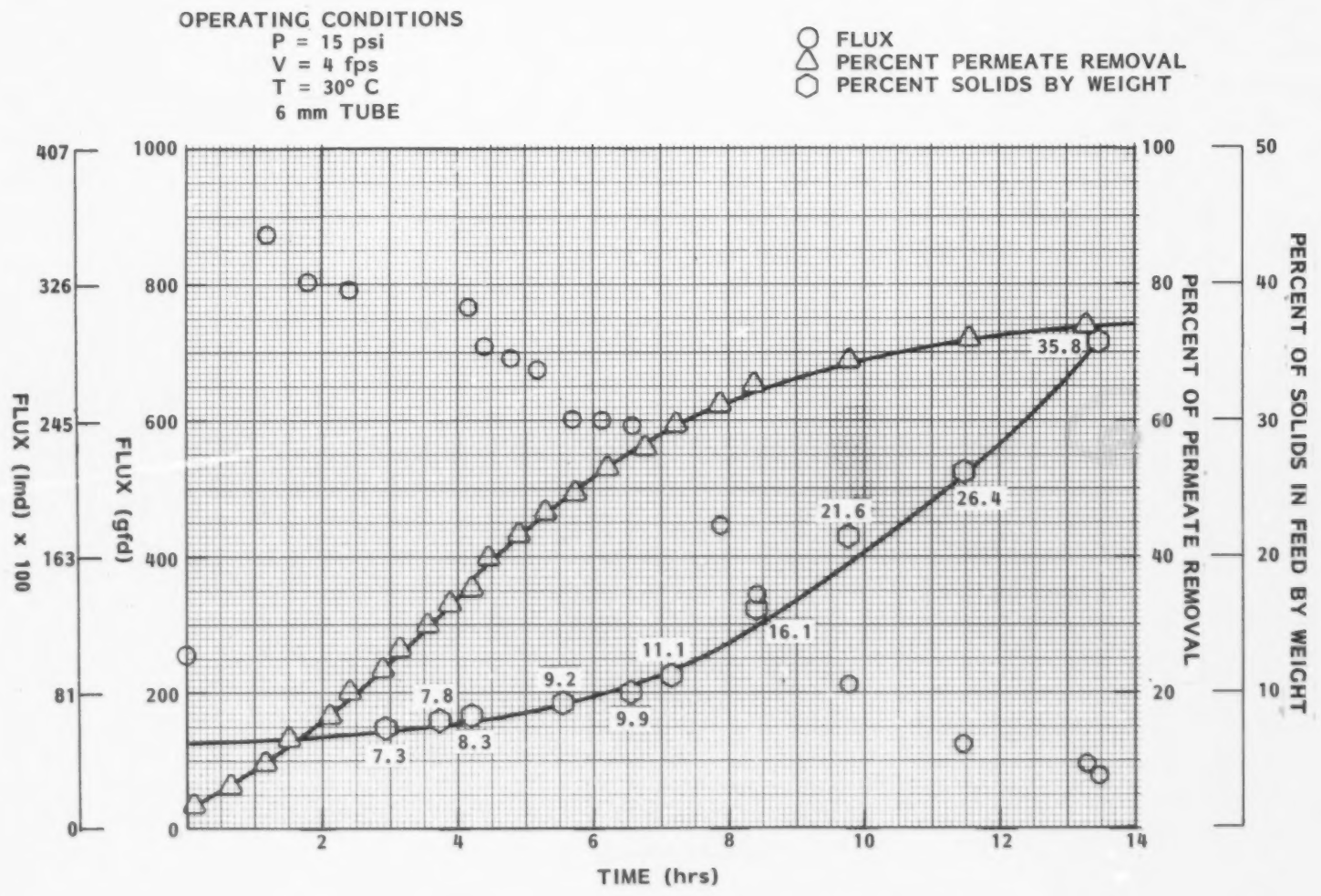

Figure 23. General Battery concentration test.

SECTION 7

PHASE II FULL-SCALE FIELD DEMONSTRATION

SYSTEM DESIGN CONSIDERATIONS

Introduction

The successful Phase I laboratory study using single tubes and modules in treating the battery manufacturing wastewater was followed by the design, construction, installation, and final field testing and demonstration of a full-scale system with on-line wastewater at the General Battery Corporation Hamburg plant site.

The basic element of the cross-flow microfiltration system is the tubular filter element. A number of steps are required in total system design starting with tube optimization and proceeding to system component selection and sizing. The tubes are assembled into modules, which can be optimized in terms of their length, diameter, number of tubes contained, type of end fitting used, and so on.

The arrangement of these modules in the system can be in series, in parallel, or in a combination of both. The criteria for selecting a particular arrangement are: ease of handling; ease of maintenance; ease of installation; power requirements; permeate production performance; as well as capital and operating costs. The principal factor which governs the modules arrangement is the permeate "productivity," which is defined as the ratio of the rate of permeate production per pass of the circulating flow through the filtration system to the rate of circulation flow itself.

In general, the productivity of most cross-flow filtration systems such as ultrafiltration and RO is quite low, less than 0.1, unlike that of thru-flow filters for which the productivity is unity. The productivity of the systems, however, may vary over a rather wide range, depending on module arrangement and operating conditions, and it is usually at a reasonably high level ($\sim$0.2-0.3).

For a tube bundle of a given length and a given number of tubes, the useful filtration surface area will increase linearly with the tube diameter, while the volume occupied by the tube bundle will increase as the square of the tube diameter. Thus, a smaller-diameter tube theoretically provides for better utilization of available space in applications which are space

constrained. Expressed differently, in a module of fixed external dimensions, a larger number of small diameter tubes can be housed to afford a larger filtration surface area than is possible with larger diameter tubes. Based upon considerations of performance and power requirements, a 6-mm tube was selected.

In the design process, the total system was designed in terms of performance (both permeate quality and flux) by the proper choice of tube pore-size distribution, tube diameter, module size, operating pressure, and feed circulation velocity. An important consideration which is relevant to the selection of the tube diameter is the pressure drop suffered by the circulating flow per unit length of tube. This has an impact on pump capacity and pipe diameter, and an ultimate impact on capital and operating costs.

The module which was constructed for the full-scale system contains ~220 six-mm tubes, with a total filtration surface area of 8.4 m^2 (90 ft^2) (Figure 24). The modules themselves make up only one part of the "total system," which includes pumps, valves, gauges, feed holding tank, sludge-thickening tank, permeate tank, module cleaning system, etc. The full-size Hydroperm system includes two modules in series with a 946 lpm (250 gpm), 7-½ hp pump, as shown in the photograph in Figure 25. The total system, as installed in the General Battery Hamburg plant is shown in Figure 26. The complete wastewater treatment system installed at this plant includes: (1) a 60,600 liter (16,000 gallon)(pre-existing) reaction tank, in which lime is stirred into the acidic wastewater to bring the pH up to a range of ~8-9; (2) a 37,800 liter (2000 gallon) permeate holding tank, from which the permeate can be discharged to the sewer or to a local stream (reuse of the permeate is an option which deserves further evaluation); (4) two units, each including two modules in series.

Hydroperm System Assembly

The modules, permeate collection tank, cleaning tank and pumps were designed to be installed on a prefabricated steel skid base. All required supporting structures were also provided as part of the same base. The system assembly process was initiated by mounting the main feed pump and permeate transfer pump on the base. The cleaning tank and the permeate collection tank are then fixed in their respective positions. With these major items in place, the connecting piping and valves are then assembled to interface with each of the above mentioned items in accordance with the design drawings. Necessary switches and gauges are also fitted into the piping arrangement. The modules are the last to be mounted on the system to complete the entire assembly.

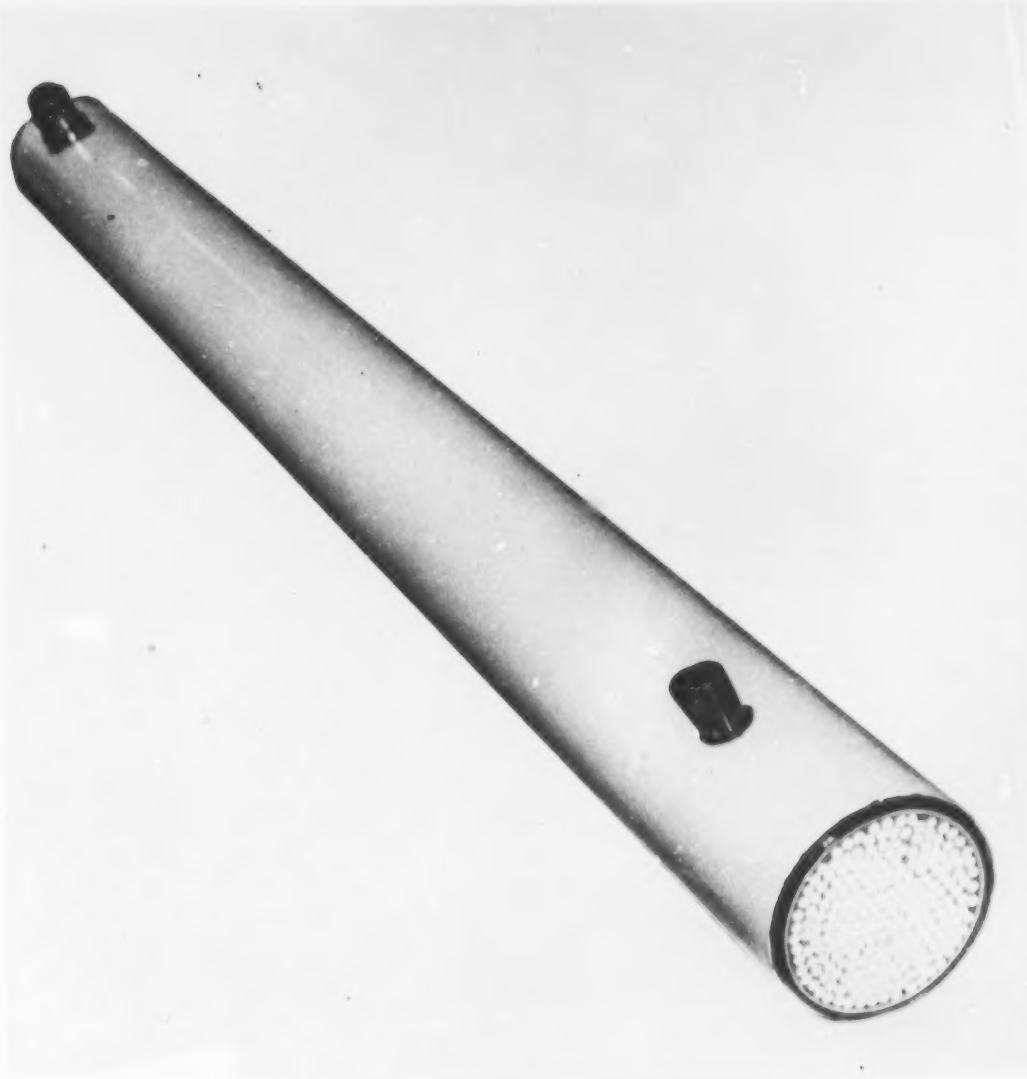

Figure 24. Microfiltration module.

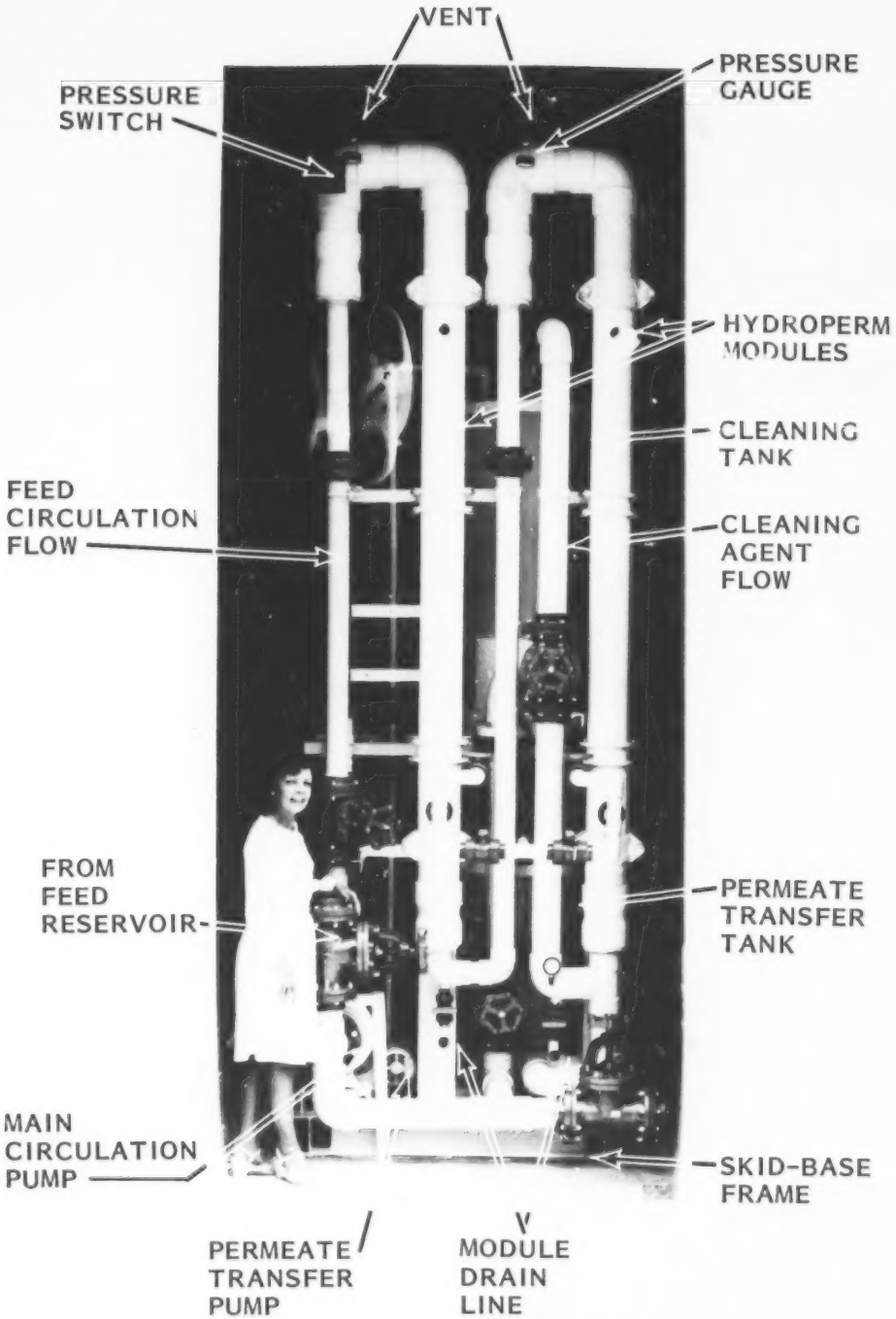

Figure 25. Two-module wastewater treatment unit.

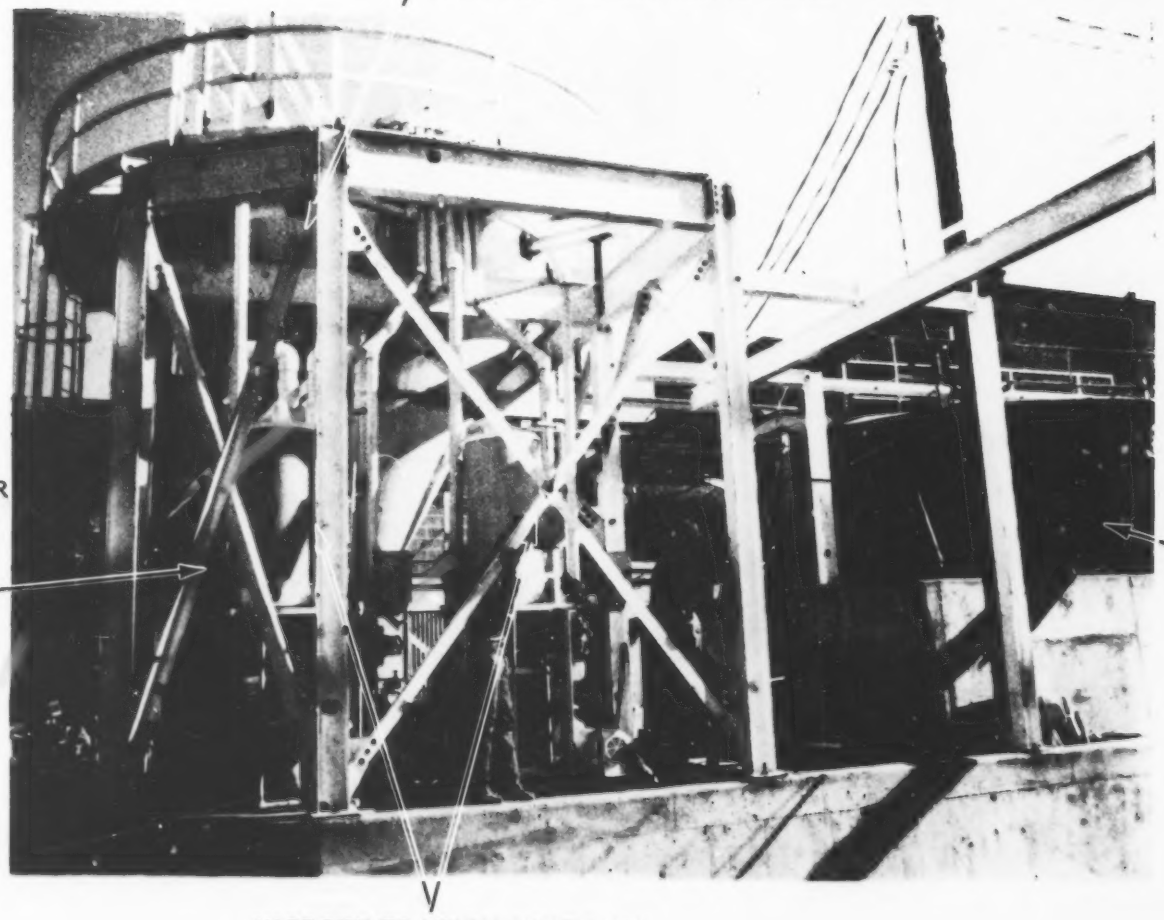
37,800 LITER (10,000-GAL) FEED CIRCULATION AND SLUDGE SETTLING CONE
7,560-LITER (2000 GAL) PERMEATE HOLDING TANK
60,600-LITER (16,000-GAL) REACTION TANK
MICROFILTRATION UNITS (2)

Figure 26. Microfiltration system at General Battery plant.

System Checkout at HYDRONAUTICS

After completion of the construction of the system, three tests were conducted: a hydrostatic test; an electrical function test; and a dynamic performance test. The purpose of the hydrostatic test is simply to check all connections for leaks. The electrical function test is to check all control switches which operate pumps, level sensors, and the pressure switches. Having satisfied the first two checkout procedures, the system is then operated in a live simulation. This test proceeds as follows. The cleaning tank is filled with water to supply the hydrostatic needs of the main feed pump. After circulating through the modules, the return flow is discharged back to the cleaning tank; the permeate in this process is collected in the permeate tank and is automatically pumped back to the cleaning tank when the former is full. Tests were conducted to evaluate the performance of each component and to detect any possible leaks in the system.

System Installation at Hamburg

When the units were shipped to the field site, a crane was used to lift the units and move them to the desired location. Leveling of the unit was then checked by a level gauge with the help of four adjustable legs on four corners of the skid base. During transportation, the cleaning tank, permeate tank and the modules were removed. They were remounted onto the unit on site. This completed the system installation on-site.

System Interfacing at Hamburg

Upon installation of the microfiltration units, interfacing of the units with the existing plant equipment was undertaken. Interfacing involved: (1) connecting the feed lines from the settling cone to the main feed circulation pumps on the unit; (2) connecting the feed returns and by-pass lines to the settling cone; (3) connecting the permeate lines from the permeate transfer pumps to the 2000-gallon permeate holding tank; (4) connecting the tap water lines for the main pump seal flushing; (5) connecting the power lines to the units through the junction box. The unit was then ready to receive the actual feed water for initial on-site checkout.

Site Preparation at Hamburg

Simultaneously with the HYDRONAUTICS' activities to design, construct, test and install the two units, General Battery Corporation was engaged in the design of the 10,000 gallon cone, selection of interface pumps, pipes, valves, and

instrumentation, and establishment of contracts for the laying of foundations, construction of the cone, fabrication of the treatment building, and installation of plumbing, electrical and instrumentation items.

Frequent meetings were held between General Battery Corporation and HYDRONAUTICS personnel to coordinate and schedule activities during the design, construction and installation phases, as well as during the later demonstration phase.

During the period July-September 1979, HYDRONAUTICS, Incorporated produced tubes and modules, and assembled and checked out the two units. Because of delays by their subcontractors, General Battery Corporation did not complete the laying of foundations, construction of the 37,800 liter (10,000 gallon) steel cone, and installation of the 7560 liter (2000 gallon) permeate tank, until November 1979. The two units were transported to the General Battery Corporation plant at Hamburg and installed at the site in November 1979. Subsequently, HYDRONAUTICS and General Battery Corporation jointly engaged in the hydraulic and electrical interface activities, which were completed in early December 1979. At that time, electrical and hydraulic tests were made to check for proper performance of the system. Construction of the building which houses the units was not complete until January 1980, at which time both units were operated with actual limed-wastewater in a preliminary checkout. However, since the insulation of the building and the heating system had not been completed, initiation of the 12-week, full-scale demonstration program had to be delayed until late February 1980.

SYSTEM OPERATION AND DEMONSTRATION AT THE HAMBURG SITE

After the microfiltration system has been installed and interfaced with the system components provided by General Battery Corporation immediately after the neutralization process, a two-week period of system checkout, debugging, and operator training was initiated. The system checkout included not only the operation of the units but also: (1) definition of the procedure which had to be followed with respect to the plant wastewater neutralization process, and transfer to the settling cone of the wastewater feed to the unit; (2) preparation of the operational manual based on both the laboratory experience and upon field operation of the unit. Thus, the manual was updated to reflect: field operating conditions; sampling procedures, techniques and frequencies; and the logistics of transporting collected waste feed and permeate samples to and from the independent analytical laboratory. Quick turn-around of laboratory results were critical in terms of the control of the operational procedures to optimize the performance of each individual module.

During the first week of operation of the unit (the week of February 25, 1980), a procedure was established on how to process the wastewater from the neutralization tank to the unit and eventually to sludge removal from the settling cone. It was found that the unit dewatering rate (permeate flux) was much higher than has been anticipated in the original design. The consequence was that only one of the two units was operated at any one time to treat the daily wastewater volume. Even then, each unit was operated only three to five hours per day. This resulted also because the battery plant was at a reduced workload level. The typical daily waste produced was only in the range of 38,000 to 57,000 liters (10,000 to 15,000 gallons), with some surges to 95,000 liters (25,000 gallons). With an average permeate production at 190 lpm (50 gpm) minimum per unit (11,400 liters, 3000 gal/hour), three hours of continuous operation of the unit would generate 38,000 liters (10,000 gallons) of permeate, suitable for direct discharge, and about 7600 liters (2000 gallons) of heavy sludge (20-35% SS by weight). Further dewatering of this sludge was theoretically possible, but there would have been a risk of plugging the 6-mm tubes, as well as a serious difficulty in discharging the sludge from the tank truck to the land-fill site. It would have seemed quite feasible to further dewater the sludge to a dry-product state by using a small filter press. This would have reduced the sludge transportation cost even further. This option is now under study.

In this initial, two-week checkout period, several modifications were made. To accommodate the high flux rate for each unit, a larger capacity permeate transfer pump and larger size piping arrangement were required. Because of the limit of space available on the skid base, one additional 1½ hp transfer pump was added to each unit to be used simultaneously to accommodate the permeate flow. The existing 1-inch size permeate piping arrangement was replaced with 2-inch pipes.

A permeate sampling port was also incorporated into each module. The old design combined the permeate flow from both modules on the unit. This modification enabled the operator to investigate the performance of each individual module during the filtration process. A feed line sampling port was also required, and was installed on the feed line at a point after the pump discharge and before the waste feed enters the first module, to facilitate sampling of the feed. Originally, the operator had to sample the feed directly from the top of the settling cone. This had required the operator to go out of the building and climb to the top of the settling cone to obtain representative feed samples. This modification enabled the operator to stay inside the building while doing the feed sampling. However, in order to obtain a truly representative sample in the pipe flow, an "isokinetic sampling procedure" was adopted.

This was necessary because of the large solids content in the feed. Failure to satisfy this requirement could have resulted in erratic samples.

During the operation with high-suspended solids feeds, it was found that the risk of plugging tubes (module) was quite high at the time of system start up and shutdown. Thus, the start up and shutdown procedures were modified as follows. In the system start up, the valves were adjusted so that the feed pump would take feed initially from the 7600 liter (2000 gallon) permeate holding tank to establish the flow through the modules. After approximately 2 minutes, the wastewater feed was gradually blended into the permeate feed flow to make a dilute solids mixture. Subsequently, the permeate feed was shut off and replaced with the full waste feed. This procedure reduced any shock load of heavy suspended solids on the modules and thus eliminated any risk of tube plugging due to heavy solids in the feed. The reverse procedure was followed for system shutdown, i.e., gradually blending permeate flow into the waste feed, and eventually closing down the waste feed flow. This latter technique was also used as the daily cleaning procedure. This process of blending in permeate and eventually replacing waste feed with permeate was used to flush residual solids in the system and thus constituted an excellent daily system cleaning procedure. This operational modification was incorporated into the operation manual for operator training.

Surfactants were used in the "lead plate formation tank" in the battery plate manufacturing process to suppress hydrogen fumes. These surfactants, however, created a foaming problem during the filtration process. Although these foams did not disrupt the unit performance, they did mess up the test site. Foam suppressant was thus used to reduce the foaming problem. Permeate quality and flux did not vary with the use of these chemicals.

The system checkout and debugging took about one week's time. After this period, operator training was begun. Five General Battery Corporation Hamburg plant employees participated in this program. They were: the plant engineer; the plant maintenance supervisor and his assistant; and two wastewater plant operators. Training began with familiarizing all personnel with every item of equipment and instrumentation, as well as with the basic principles of cross-flow microfiltration. This was followed with hands-on experience in operating the unit. An operational manual was distributed to each participant. Step-by-step trace of the filtration cycle and the cleaning procedure cycle were demonstrated with the unit, as set forth in the manual.

Starting the second week, the units were operated by the plant personnel, with the supervision of HYDRONAUTICS personnel. The operator had no trouble in operating both units. Because of the relative ease of operation of the units, the same operator is also assigned the responsibility of taking care of the waste acid neutralization process. HYDRONAUTICS personnel remained at the plant site for another two weeks to demonstrate various tube/module cleaning techniques and to assure that correct sampling and operating procedures were followed.

Hamburg plant operators took responsibility beginning with the fifth week of the field test. Close communication between plant operators and HYDRONAUTICS personnel was maintained. There were no major difficulties in operating the unit, and the cleaning procedures set forth in the operational manual consistently restored flux to initially high values.

SYSTEM PERFORMANCE IN THE FIELD

Sampling Procedures

During the two-week checkout and ten-week demonstration program, extensive data were taken on the permeate flux rates and the permeate quality. The permeate sampling frequency was followed according to a schedule approved by the Environmental Protection Agency Project Officer. Gilbert Associates, Inc., an independent analytical laboratory in Reading, Pennsylvania, performed the analyses under contract. During the first two weeks, feed and permeate were sampled once per hour. Later, the sampling frequency was reduced, and, in accordance with the schedule, (beginning on March 25, 1980), feed samples were taken at the first and second hour of operation; permeate samples were taken at the first hour of operation from each module of the unit; and at the second hour of operation only combined samples were taken; one sludge sample was taken at the end of each day's run. Later in the program, the laboratory analyses were conducted by the General Battery Corporation analytical laboratory. Once a week, however, an identical sample was also analyzed by Gilbert Associates, Inc. to confirm the validity of General Battery's analytical results. During the last eight weeks, the daily parameters to be measured and evaluated were limited to pH, DS, SS and Pb. Only one sample was analyzed weekly for all metals.

Permeate Flux

Initial daily flux values were typically in the range of 32,600 lmd (800 gfd) leveling off to 16,300-20,400 lmd (400-500 gfd) after several hours of operation. The flux was readily restored to the initial value by cleaning the modules for several minutes

daily with permeate. Cleaning with dilute HCℓ (~2%) was practiced generally only on a weekly basis.

The flux performance curves for each module are presented in Figures 27, 28, 29 and 30. The effectivenss of HCℓ cleaning is clearly illustrated in these figures.

High flux rates mean rapid dewatering rates of the feed. In other words, the feed is continuously being concentrated as it flows through the tube, while clear water is being removed. If the dewatering rate is too high, the circulating feed will have a high solids concentration and create a potential risk of tube plugging by the solids in the feed towards the end of the second module. This should be avoided. Thus, a decision was made to throttle the permeate valves so as to limit the permeate removal rate. It was found that a permeate flow of 190 lpm (50 gpm) per unit, or 95 lpm (25 gpm) per each module, was an acceptable value to effectively limit the solids concentration in the feed, and yet provide reasonably high permeate production. The permeate valves were opened fully only when the flux rate declined after hours of operation, as a sludge membrane built up on the tube wall. At such times, module cleaning was usually required either by permeate flushing or by HCℓ cleaning. The flux values for throttled permeate production and for cleaning cycles are reflected in the above mentioned figures. Later, in order to evaluate the module performance more carefully, the flux measurements were taken when permeate valves were temporarily fully opened. During the routine filtration cycle, however, these valves were throttled as needed.

At these high flux levels, production of permeate by only one unit is in the range of 13,200 to 18,900 liter/hr (3500 to 5000 gal/hr) during a flitration run of several hours duration. Typically, a load of 94,600 liters (25,000 gallons) of wastewater is filtered in 4½ to 5 hours by only one unit, producing 75,700 liters (20,000 gallons) of clear permeate and 18,900 liters (5000 gallons) of sludge. The solids content of the sludge is in the range of 20-35% SS by weight.

Permeate Quality

The permeate is very clear. Tables 9 and 10 show the analytical results from the independent laboratory (Gilbert Associates, Inc.) as well as the General Battery laboratory on the lead and suspended solids for both units. Tables 11-A and 11-B show the analytical results for all heavy metals and solids.

Study of these tables indicates that suspended solids in the feed, ranging from tens of thousands of ppm to as high as 180,000 ppm, were typically reduced to <5 ppm in the permeate.

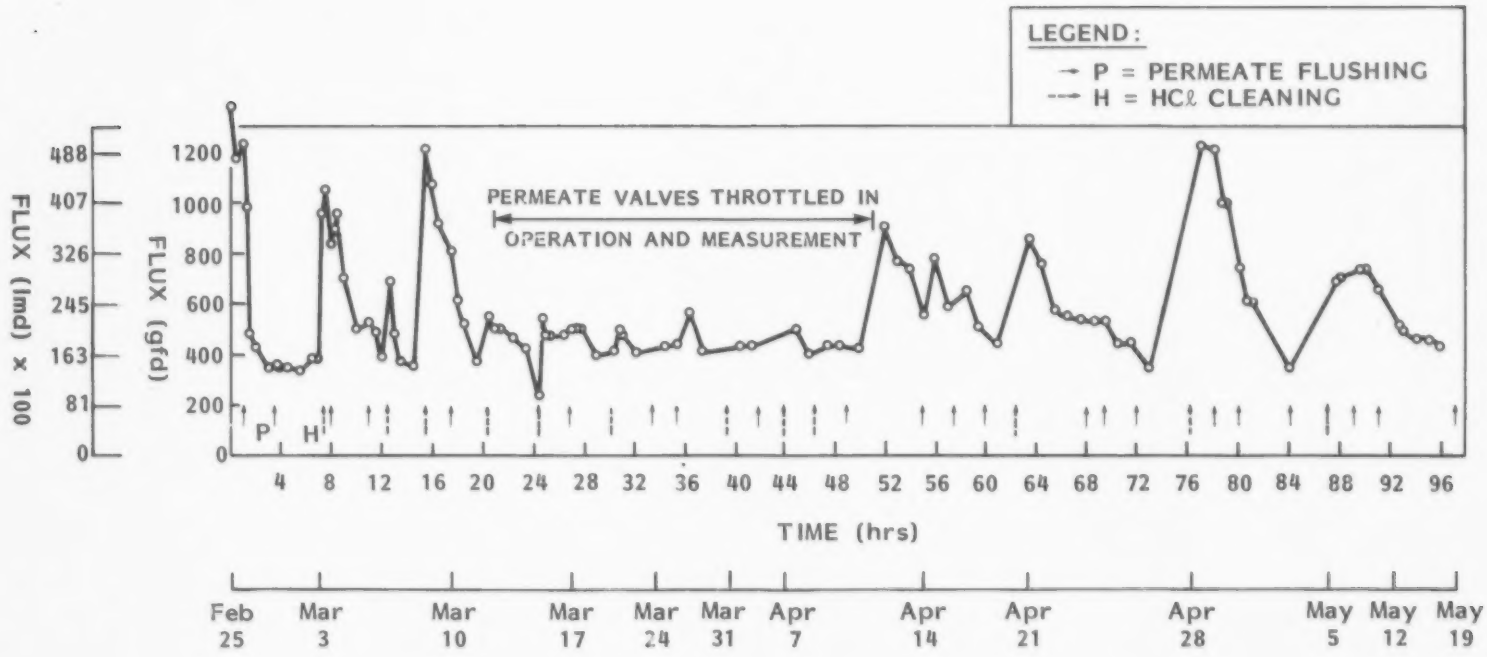

Figure 27. Full-scale system flux performance - Module 2.

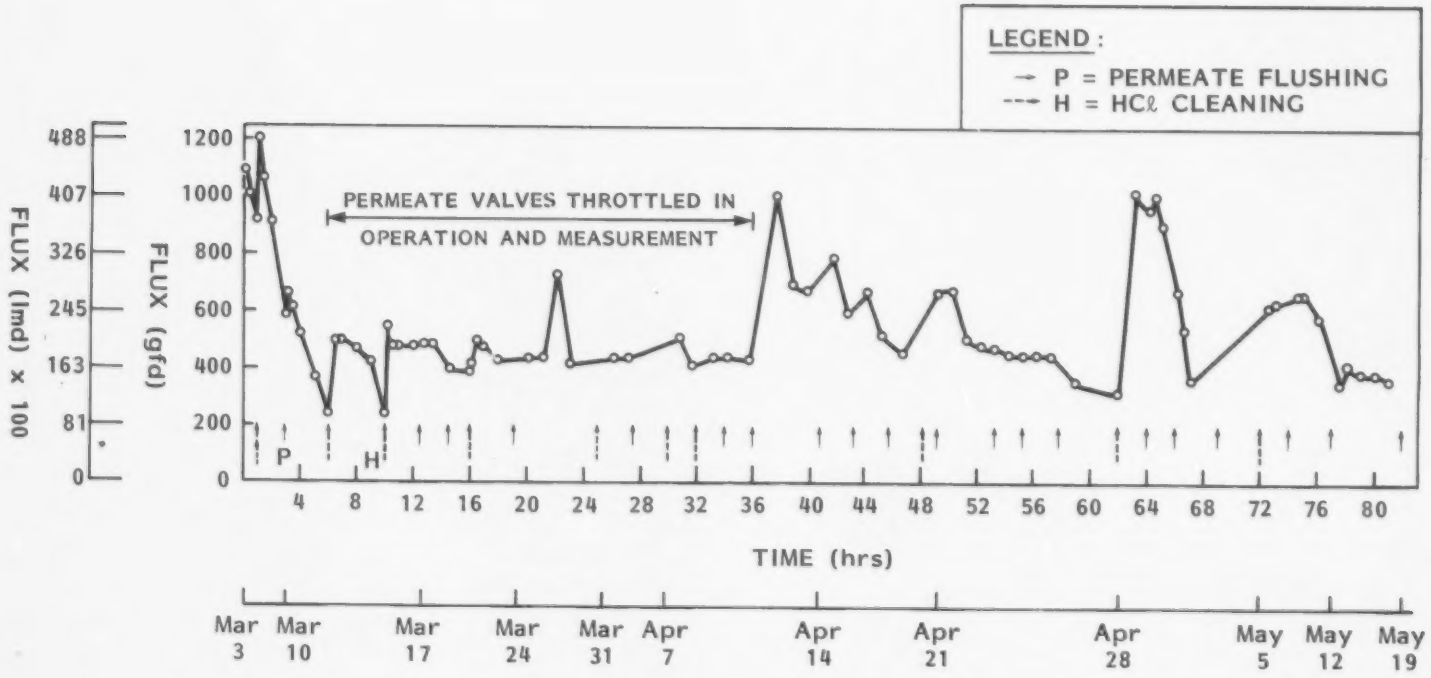

Figure 28. Full-scale system flux performance - Module 5.

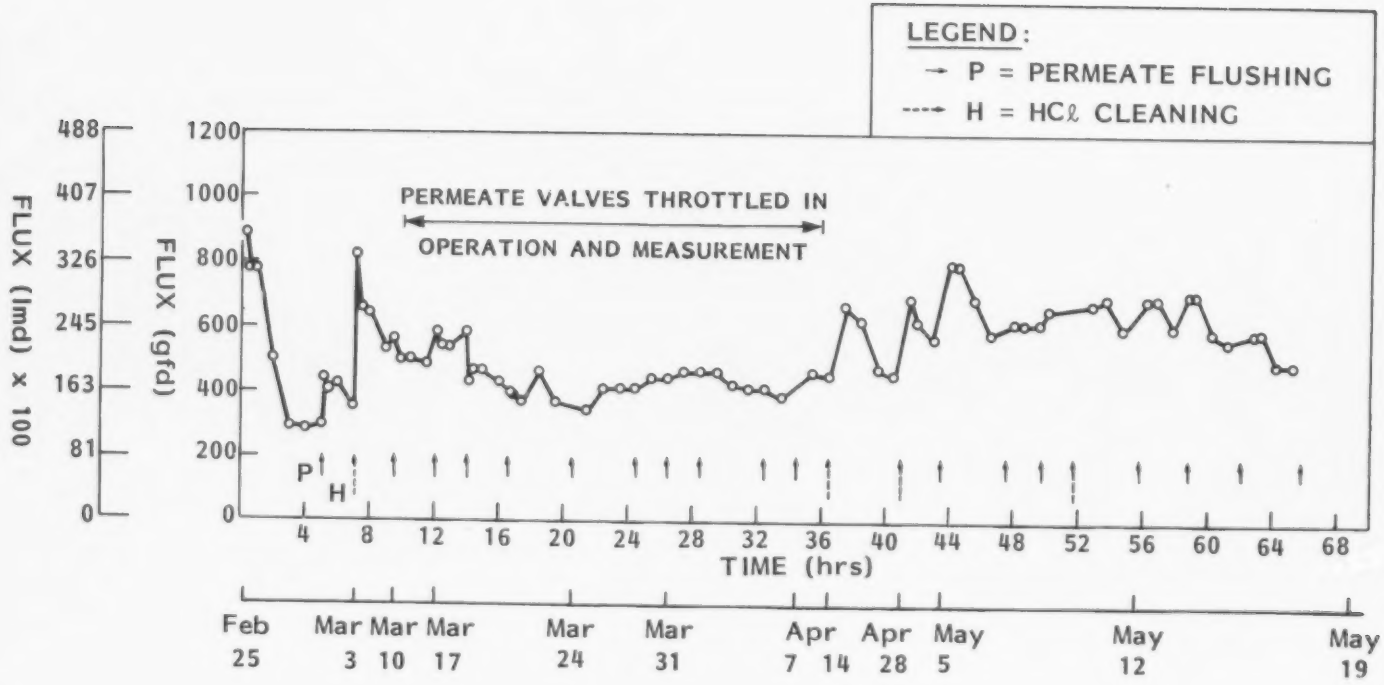

Figure 29. Full-scale system flux performance - Module 3.

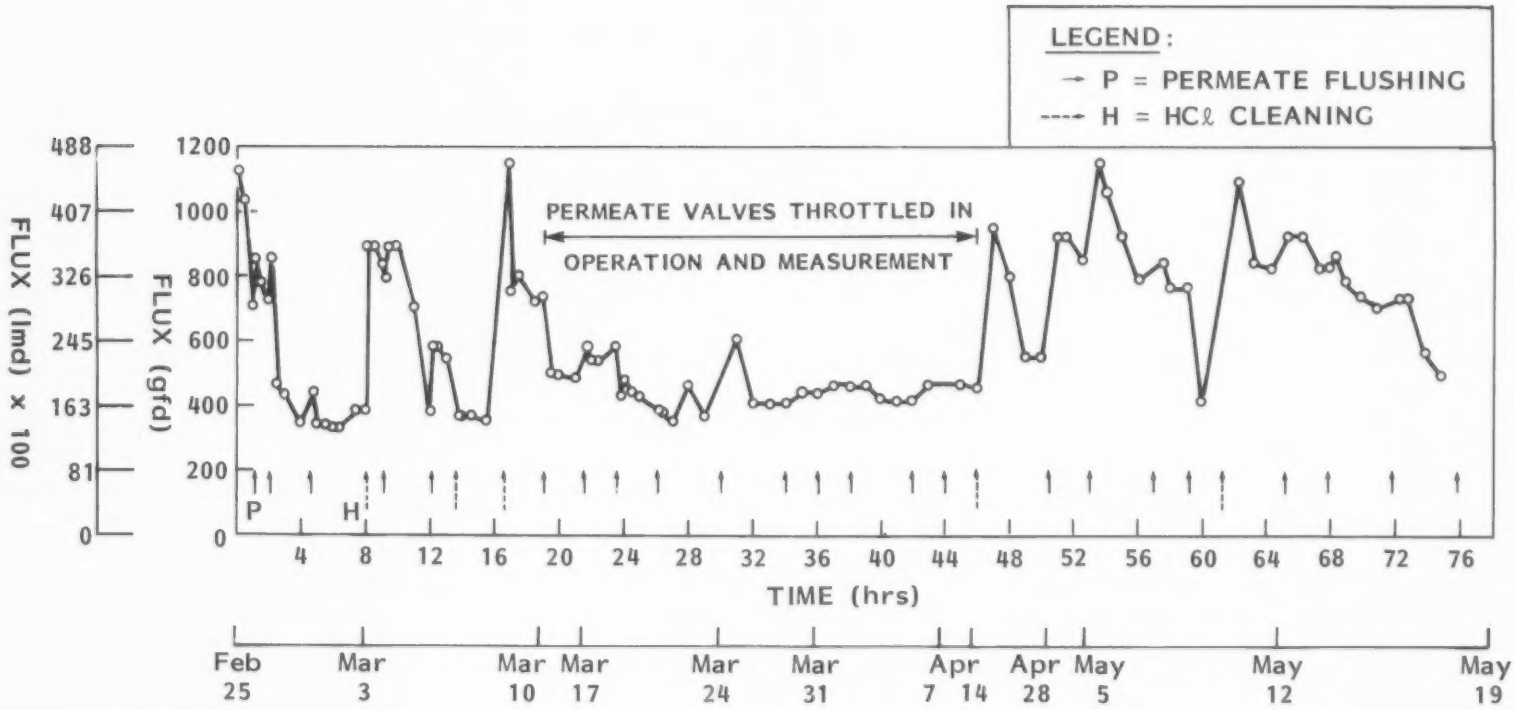

Figure 30. Full-scale system flux performance - Module 6.

TABLE 9. LABORATORY ANALYSES OF FEED AND PERMEATE QUALITY - FULL-SCALE DEMONSTRATION - UNIT NO. 1, MODULES NO. 2 AND 5

LEAD AND SOLIDS (ppm)

Date	Actual Time	Total Elapsed Time (hr) Module No.2	Module No.5	Cone Feed pH	Cone Feed Pb	Cone Feed SS	Module No. 2 pH	Module No. 2 Pb	Module No. 2 SS	Module No. 5 pH	Module No. 5 Pb	Module No. 5 SS	Sludge SS
Feb. 27,'80	1000	0.5		8.4	16.1	1,250	8.3	0.094	2				
	1030	1.0		9.3	696	182,000	8.2	0.045	1.8				
Feb. 28,'80	1200	2.0		9.0	122	14,200	8.8	0.082	<0.5				
	1300	3.0		9.1	212	24,400	8.9	0.053	<0.5				315,000
Feb. 29,'80	1100	4.0		8.0	68.8	16,700	8.2	0.088	1.0				
	1130	4.5		8.9	70.8	19,500	8.6	0.072	1.0				
	1230	5.5		9.0	85.4	21,900	8.6	0.064	0.8				
	1330	6.5		-	221	37,300	-	0.060	<0.5				
	1400	7.0		7.1	261	233,000	8.6	0.060	<0.5				
Mar. 3, '80	1015	7.25		9.2	39.0	15,700	7.7	0.173	0.8				
	1030	7.5		9.0	34.8	16,600	7.9	0.311	1.0				
	1100	8.0		8.9	29.2	11,600	8.1	0.195	1.4				
Mar. 4, '80	0815	8.25		10.1	111	13,700	9.4	0.254	14.8				
	0830	8.5		10.1	54.2	24,600	9.8	0.187	10.4				
	0900	9.0		10.1	88.6	22,600	9.7	0.311	10.0				
	1000	10.0		10.0	154	41,000	9.6	<0.04	1.2				
Mar. 5, '80	0815	11.25		8.6	436	14,100	8.7	0.091	<0.5				
	0830	11.5		7.8	518	19,300	8.0	0.073	<0.5				
	0900	12.0		8.3	766	19,600	8.3	0.086	0.8				
Mar. 6, '80	1000	13.0		8.0	252	14,200	8.4	0.191	1.2				
	1030	13.5		2.5	273	11,400	2.1	0.227	1.0				
	1130	14.5		3.4	323	16,400	8.3	0.250	1.8				
Mar. 7, '80	1030	16.0	1.5	2.2	14.8	19.8	4.0	0.80	2.0	7.6	0.89	4.6	
	1100	16.5	2.0	7.6	22.2	401	7.7	0.659	2.4	7.8	0.739	3.2	
	1200	17.5	3.0	9.1	106	21,300	9.2	0.135	<0.5	9.5	0.094	<0.5	
Mar. 11,'80	0900	18.0	3.5	10.4	5.15	1,250	10.3	0.30	15.8	10.3	0.332	1.4	
	0930	18.5	4.0	10.3	2.63	501	10.3	0.30	6.8	10.3	0.289	2.6	
	1030	19.5	5.0	10.4	5.67	935	10.3	0.253	17	10.3	0.268	2.2	
	1130	20.5	6.0	10.0	102	41,100	9.7	0.20	9.2	9.7	0.210	2.0	325,000
Mar. 12,'80	0915	21.0	6.5	7.6	9.0	1,300	8.1	0.279	4.0	8.1	0.458	<0.5	
	0945	21.5	7.0	7.7	9.2	1,130	8.3	0.117	5.2	8.1	0.337	0.6	
	1045	22.5	8.0	7.7	58.4	12,600	8.3	0.130	<0.5	8.4	0.230	<0.5	
	1145	23.5	9.0	8.1	132	26,100	8.4	0.102	<0.5	8.5	0.147	<0.5	
	1245	24.5	10.0	8.2	140	12,400	8.4	0.064	1.3	8.3	0.182	23.5	309,000
Mar. 14,'80	0900	25.0	10.5	9.2	33.2	3,890	9.5	0.11	15.3	9.6	<0.04	0.8	
	0930	25.5	11.0	9.4	30.8	3,610	9.6	0.12	17.3	9.8	0.088	<0.5	
	1030	26.5	12.0	9.6	95.0	8,820	9.8	0.19	30.5	9.8	0.046	<0.5	273,000
Mar. 18,'80	0900	27.5	13.0	11.2	26.4	11,200	11.2	0.329	1.5	11.2	0.324	1.0	
	0930	28.0	13.5	11.2	16.6	6,860	11.3	0.278	24.5*	11.2	0.278	22.8*	
	1030	29.0	14.5	11.2	25.2	37,800	11.3	0.208	1.5	11.3	0.241	1.5	217,000
Mar. 20,'80	1115	30.75	16.5	8.6	140.	43,500	9.5	<0.04	<0.5	9.0	<0.04	16.5	
	1145	31.25	17.0	8.3	156.	46,100	8.4	0.088	1.3	8.4	<0.04	1.3	
	1245	32.25	18.0	8.6	193.	66,600	8.7	0.061	15.8	9.1	<0.04	1.5	148,000
Mar. 27,'80	0900	34.5	20.25	7.6	9.24	828	8.08	0.13	7.0	8.10	0.10	7	304,996
Mar. 28,'80	0900	36.5	22.25	9.36	3.73	78	9.44	0.028	3	9.45	0.014	5	244,344
Apr. 2, '80	0900	40.5	26.25	7.51	27.7	8,121	7.64	0.30	24 *	7.35	0.51	46 *	32,700
Apr. 7, '80	0900	45.0	30.75	8.10	24.0	2,242	8.74	0.36	37 *	8.70	0.38	42 *	251,364
Apr. 9, '80	0930	47.5	33.25	9.53	3.03	202	9.92	0.17	6	9.87	0.13	0	76,428

* Probably contaminated sample bottles.

TABLE 10. LABORATORY ANALYSES OF FEED AND PERMEATE QUALITY - FULL-SCALE DEMONSTRATION - UNIT NO. 2, MODULES NO. 6 AND 3

LEAD AND SOLIDS (ppm)

Date	Actual Time	Total Elapsed Time (hr)		Cone Feed			Module No. 6			Module No. 3			Sludge
		Module No.6	Module No.3	pH	Pb	SS	pH	Pb	SS	pH	Pb	SS	SS
Feb. 25,'80	1030		0	9.3	12.2	4,000				9.3	0.27	<0.5	
	1230		2.0	9.2	89.4	11,980				8.8	0.17	0.06	
	1530		5.0							8.6	0.10	4	
Feb. 26,'80	1345	0.5		9.1	100	14,300	7.0	0.29	0.6				
Feb. 27,'80	1000	1.5		8.4	16.1	1,250	7.7	0.074	1.8				
	1030	2.0		9.3	696	182,000	7.8	0.026	1.6				
	1345		5.5	8.9	224	172,000				8.0	0.064	1	
	1415		6.0	8.5	39.1	7,160				8.3	0.042	1.4	
	1515		7.0	9.0	141	14,500				8.3	0.061	2	
Feb. 28,'80	1200	3.0		9.0	122	14,200	8.5	0.091	1.2				
	1300	4.0		9.1	212	24,400	8.9	0.094	<0.5				
Feb. 29,'80	1100	5.0		8.0	68.8	16,700	-	0.10	<0.5				
	1130	5.5		8.9	70.8	19,500	8.7	0.064	1.5				
	1230	6.5		9.0	85.4	21,900	8.5	0.05	0.6				
	1330	7.5		-	221	37,300	8.9	0.084	<0.5				
	1400	8.0		7.1	261	233,000	7.8	0.056	6.0				
Mar. 3, '80	1015	8.25		9.2	39	15,700	7.9	0.196	0.8				
	1030	8.5		9.0	34.8	16,600	7.7	0.784	1.8				
	1100	9.0		8.9	29.2	11,600	7.9	0.566	1.2				
Mar. 4, '80	0815	9.25		10.1	111	13,700	9.7	<0.04	0.8				
	0830	9.50		10.1	54.2	24,600	9.7	<0.04	0.6				
	0900	10.0		10.1	88.6	22,600	9.5	<0.04	<0.5				
	1000	11.0		10.0	154	41,000	8.9	0.052	<0.5				
Mar. 5, '80	0815	12.25		8.6	436	14,100	8.7	0.132	<0.5				
	0830	12.50		7.8	518	19,300	8.2	0.123	0.6				
	0900	13.0		8.3	766	19,600	8.4	0.091	<0.5				
Mar. 6, '80	1000	14.0		8.0	252	14,200	8.4	0.191	1.2				
	1030	14.5		-	273	11,400	-	0.214	1.0				
	1130	15.5		-	323	16,400	-	0.345	1.2				
Mar. 7, '80	1230	17.0	7.5	9.4	112	29,200	9.6	0.11	<0.5	9.5	0.08	<0.5	
	1300	17.5	8.0	9.4	141	32,200	9.6	0.023	<0.5	9.6	0.10	<0.5	
	1400	18.5	9.0	9.7	157	25,000	9.9	0.07	<0.5	9.9	0.12	<0.5	363,000
Mar. 13,'80	1000	19.5	10.0	12.0	90.5	18,500	12.1	2.5*	0.5	12.1	2.02*	1.8	
	1030	20.0	10.5	12.0	76.0	14,500	12.1	2.62*	0.5	12.1	2.82*	1.0	
	1130	21.0	11.5	12.0	117.0	22,400	12.1	2.06*	0.8	12.1	2.36*	1.8	250,000
Mar. 17,'80	1030	22.0	12.5	8.2	2.81	264	9.1	0.092	1.8	9.1	0.211	2.3	
	1100	22.5	13.0	8.2	6.4	648	9.0	0.075	4.0	9.0	0.193	3.5	
	1200	23.5	14.0	8.0	16.4	1,390	8.9	0.066	2.8	9.0	0.123	3.0	214,000
Mar. 19,'80	0900	24.0	14.5	7.7	49.6	7,380	8.1	0.185	1.0	8.1	0.324	1.0	
	0930	24.5	15.0	7.6	49.6	4,950	8.1	0.120	1.5	8.1	0.190	1.8	
	1030	25.5	16.0	7.6	47.4	4,300	7.9	0.181	0.8	7.9	0.232	1.8	
Mar. 20,'80	1000	26.5	17.0	7.7	76.8	16,100	8.3	0.079	1.3	8.6	<0.04	1.0	
	1030	27.0	17.5	8.2	96.5	19,000	9.3	<0.04	1.5	9.6	<0.04	1.0	
	1130	28.0	18.5	8.4	162.0	37,300	8.8	<0.04	0.5	8.5	0.048	1.0	
	1230	29.0	19.5	8.3	200.0	65,700	7.9	<0.04	2.5	8.8	<0.04	1.3	
	1330	30.0	20.5	9.1	243.0	87,300	9.2	0.069	1.5	9.4	<0.04	1.3	148,000
Mar. 25,'80	1000	31.0	21.5	9.05	23.1	3,747	9.27	0.068	0	9.26	0.041	0	328,140
Mar. 26,'80	0900	35.0	25.5	9.39	17.8	1,831	9.34	0.19	5	9.62	0.071	8	270,548
Mar. 31,'80	0900	37.0	27.5	9.14	3.38	63	9.65	0.054	2	9.66	0.054	5	188,912
Apr. 1, '80	0900	39.0	29.5	9.49	22.2	598	10.24	0.10	5	10.19	0.071	3	343,592

* Note high pH = >12

TABLE 11-A. LABORATORY ANALYSES OF FEED AND PERMEATE QUALITY - FULL-SCALE SYSTEM DEMONSTRATION

ALL METALS AND SOLIDS

	TS (mg/ℓ)	SS (mg/ℓ)	Pb (mg/ℓ)	Cu (mg/ℓ)	Zn (mg/ℓ)	Ni (mg/ℓ)	Sb (mg/ℓ)	As (mg/ℓ)
Feb. 27, '80								
FEED	162,740	160,000	696	3.83	54.5	3.26	3.36	1.94
FILTRATE	3,621	1.8	0.045	0.017	0.008	0.024	0.141	0.002
Feb. 28, '80								
FEED	17,140	14,200	122	0.440	-	0.390	1.000	0.168
FILTRATE	3,141	1.2	0.091	0.015	0.021	0.041	0.150	<0.002
Feb. 29, '80								
FEED	22,610	19,500	70.8	0.200	0.333	0.381	0.714	0.084
FILTRATE	3,541	1.5	0.064	0.014	0.086	0.071	0.119	<0.002
Mar. 4, '80								
FEED	27,260	24,600	54.2	0.330	0.880	0.400	1.35	0.172
FILTRATE	2,980	0.6	<0.040	0.015	0.007	0.032	0.292	<0.002
Mar. 5, '80								
FEED	17,150	14,100	436	0.217	0.530	0.280	1.14	0.068
FILTRATE	3,070	<0.5	0.091	0.015	0.048	0.017	0.159	<0.002
Mar. 7, '80								
FEED	27,890	25,000	157	0.690	0.630	0.480	1.750	0.203
FILTRATE	3,130	<0.5	0.07	0.015	0.006	0.024	0.150	<0.002
Mar. 12, '80								
FEED	15,800	3,200	58.4					
FILTRATE	3,640	<0.5	0.130	0.019	0.006	0.055	0.091	<0.002
Mar. 14, '80								
FEED	11,580	8,820	95.0					
FILTRATE	2,960	<0.5	0.046	0.019	<0.002	<0.010	0.107	<0.002
Mar. 17, '80								
FEED	4,230	1,390	16.4					
FILTRATE	2,992	2.8	0.066	0.028	<0.002	<0.010	0.180	<0.002
Mar. 20, '80								
FEED	68,750	65,700	200					
FILTRATE	3,292	2.5	<0.04	0.019	0.047	<0.010	0.115	<0.002

(cont'd)

TABLE 11-B. LABORATORY ANALYSES OF FEED AND PERMEATE QUALITY - FULL-SCALE SYSTEM DEMONSTRATION

ALL METALS AND SOLIDS

	TS (mg/ℓ)	SS (mg/ℓ)	Pb (mg/ℓ)	Cu (mg/ℓ)	Zn (mg/ℓ)	Ni (mg/ℓ)	Sb (mg/ℓ)	As (mg/ℓ)
Mar. 26, '80								
FEED	14,276	11,606	30.3					
FILTRATE	2,833	2	0.029	0.007	0.001	<0.005	0.245	<0.002
Apr. 2, '80								
FEED	12,364	9,188	319.4					
FILTRATE	3,378	1	0.029	-	-	-	0.151	<0.002
Apr. 9, '80								
FEED	3,562	615	9.24					
FILTRATE	2,983	8	0.18	0.012	0.002	<0.005	-	-

Lead was reduced from several hundred ppm in the feed to ~0.02 to 0.10 ppm in the permeate, when the pH of the feed was properly adjusted, i.e., in the range of 8.5-9.5. As it happended in the day-to-day operation in the field, pH varied between <8 and >10, with the result that higher dissolved lead content appeared in the permeate. When the pH was poorly adjusted, i.e., either below 8 or above 10, much of the lead would be still in the dissolved state and consequently passed through the Hydroperm tubes as dissolved solids. A summary of laboratory analyses for lead and suspended solids from the twelve weeks of field tests is given in Figure 31.

It was found, however, that the sample collection and handling technique can have a profound impact on the analytical results. Contamination of samples can result either from poorly cleaned sampling bottles, or from the mishandling of the samples while collecting them. Clearly, the concentration of pollutants in the permeate are only in the range of parts per million. Extreme care in permeate sampling procedures is essential. It is believed both by General Battery Corporation and by HYDRONAUTICS, Incorporated, that some of the high SS values (>10 ppm) and Pb values (>0.5 ppm) may have resulted from improper sampling. A typical Gilbert Associates, Inc. certified laboratory analysis is shown in Table 12.

Figure 31 shows the frequency of occurrence for lead and suspended solids contents analyzed during present field investigation. It indicates that the majority of the lead concentration in the permeate is below 0.5 ppm. For properly controlled pH adjustment in the neutralization process, lead concentration can be easily reduced to less than 0.2 ppm. This is because most of toxic metals are amphoteric. They can subsequently precipitate out in the permeate if pH varies. This can also contribute higher suspended solid concentration in the permeate. The suspended solid concentration plot shows that more than two-thirds of permeate samples analyzed have concentration less than 3 ppm.

The State of Pennsylvania discharge permit requires a maximum daily lead limit of 0.5 ppm, and a monthly average of 0.14 ppm. The maximum daily SS limit is 40 ppm, and a monthly average is 20 ppm. The long-term performance of the demonstration unit clearly meets all the limits set forth by the State permit, so that the quality of the permeate is quite suitable for direct discharge to the environment under existing State of Pennsylvania regulations.

Sludge Generation

Waste sludge production is typically about 17,000 liters (4500 gallons) for every two days of operation, with suspended

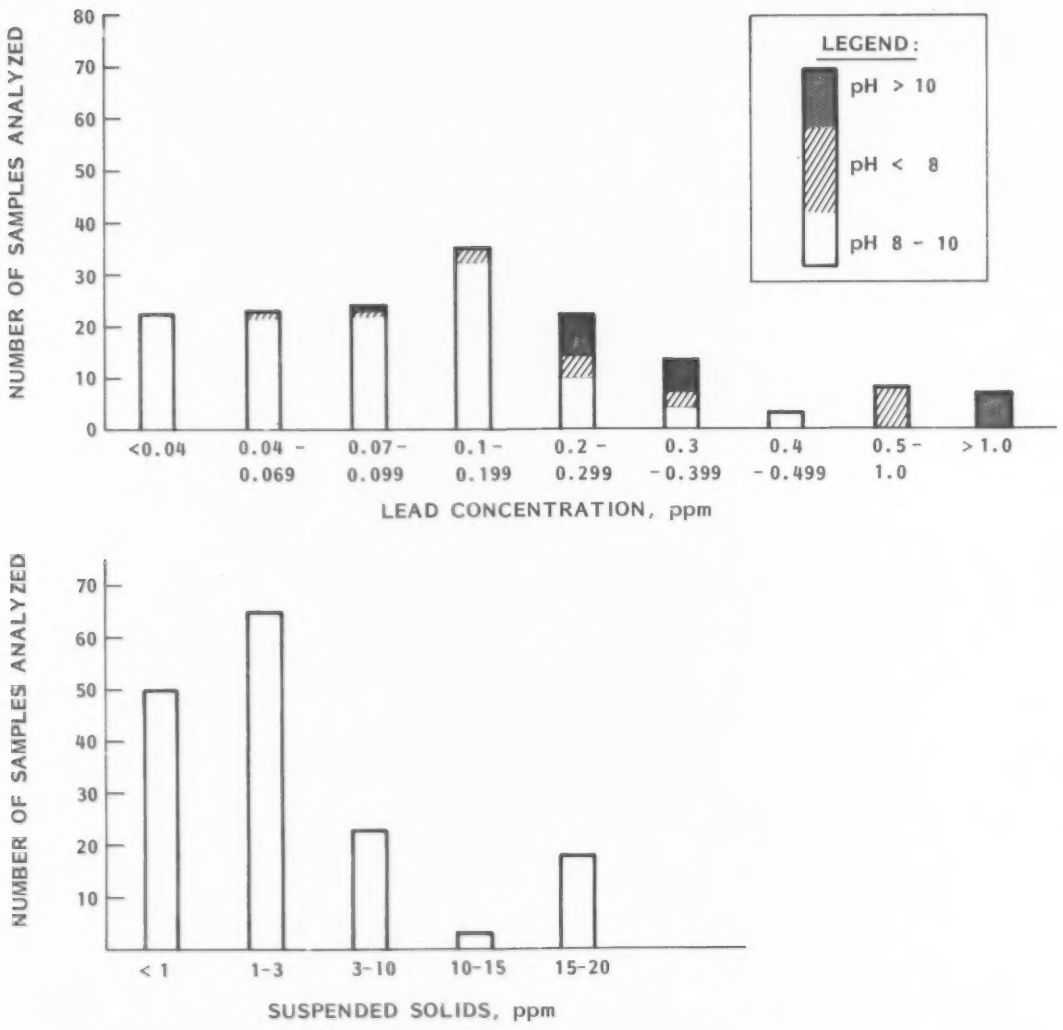

Figure 31. Pb and SS concentration in permeate from lead-acid battery wastewater.

Gilbert/Commonwealth engineers and consultants

LABORATORY SERVICES
30 NOPLE STREET, READING, PA 19611

GILBERT ASSOCIATES, INC., P. O. Box 1498, Reading, PA 19603/Tel. 215 775-2600

CERTIFICATE OF ANALYSIS

LABORATORY NO: 316761-63 RECEIVED: 3/21/80 REPORTED: 3/28/80

CLIENT: General Battery Corp, Seventh & Penn Sts.
Reading, PA 19601

SAMPLE DESCRIPTION: Analyses of Industrial Wastewater
316761 - Perm Mod 6, Sample 239, Complete, 12:30 PM
316762 - Perm Mod 3, Sample 240, Complete, 12:30 PM
316763 - Feed, Sample 241, 12:30 PM
Sampled 3/20/80

- - - - - - - -

Laboratory No.		316761	316762	316763
Antimony	mg/l Sb	0.115	0.115	
Arsenic	mg/l As	<0.002	<0.002	
Copper	mg/l Cu	0.019	0.016	
Lead	mg/l Pb	<0.040	<0.040	200
Zinc	mg/l Zn	0.047	<0.002	

Respectfully submitted,

J. K. Kieffer, Supervisor
Laboratory Services

MAH
cc: J. Buransky (2)

Table 12. Typical laboratory analysis.

solids concentrations of 20-35% by weight. The wastewater generated at the plant during a typical two-day period is about 94,600 liters (25,000 gallons). From these wastes, approximately 75,700 liters (20,000 gallons) of clear permeate are produced. One tank truck load of sludge is thus transported to the land-fill site in Reading every other day. This greatly reduces the trips which the tank truck had to make in the past (previously, two to three trips were required daily). The clean permeate is now being discharged directly to a local stream. The reuse of this high quality permeate water for plant use is now under evaluation.

SECTION 8

ECONOMIC FACTORS

CAPITAL COSTS

Hydroperm represents new, advanced wastewater treatment technology, and no final economic analyses have been made of the complete range of costs of the technology for specific use in the wide range of wastewater treatment applications. Such analyses would have to take into account such factors as feed characteristics, permeate quality requirements, system productivity, modules-configuration, actual flux rates, operating conditions, cleaning requirements, etc.

However, a general preliminary economic projection indicates the magnitude of capital equipment costs at less than $.13/liter day ($0.50/galday), (1980 dollars). These costs do not include the land, building foundation, or special reaction and holding tanks or consulting-engineering services. Including costs of transportation, installation, recirculation tank, permeate tank, etc., capital costs should still be approximately $0.26/liter-day ($1.00/gal-day). Costs do include pumps, motors, piping, pressure regulators, valving, level controls, steel work, labor, as well as the modules. New improved design studies currently being conducted should result in a substantial reduction in capital costs. These studies take into consideration variation in design parameters, and will result in the establishment of a series of cost-effective system designs for a wide range of daily wastewater treatment volumes. The operating costs are projected to be $0.13/1000 liter ($0.50/1000 gal). As improvements in the system occur the operating cost may decrease slightly.